A TREATISE ON

BUILDING CONSTRUCTION

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by

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The Late Mr. CLAUDE BATLEY

A. R. I. B. A

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FOREWORD

THE writing of a treatise on Building Construction within a compass of 300 pages or so is a formidable task, and one which no two authors would tackle in precisely the same way; there is so much that must needs be omitted, and to deal with what is left in any kind of a logical order is a further problem.

When Professor Deshpande requested me to write a foreword I was flattered but frightened, but the thought of the young Indian Students who have chosen Civil Engineering or Architecture as their career, and the knowledge of how badly they are served with suitable text-books moved me to consent, feeling that the present volume would provide, at least an interesting introduction to the everyday constructional side of their studies.

It is also a great advantage to have a book written by an Indian whose own practice has been in India itself.

As one who was born and bred in a brick district in England, and who has admired the beautiful, honest brick treatments of many an old Indian town, I would, however, cross swords with Mr. Deshpande when he writes, "While stone is a natural building material, brick is artificial, a product manufactured in imitation of stone; brick is a comparatively flimsy material and plastering is only a camouflage to conceal its defects."

Instead of accepting such "flimsy" stuff as nowadays passes under the name of brick in so many parts of India, and costs our clients so much, both in the necessity of protecting it with plaster on account of its high absorption and, also, in increasing its thickness on account of its low bearing stress, both not inherent defects but entirely due to slovenly and indifferent manufacture, it is surely up to us, Architects and Civil Engineers alike, to insist on the eradication of these defects, rather than their acceptance as inevitable.

Mr. Deshpande, as a Civil Engineer, flatters us too much with the term "architectural effect," a term which no architect, worthy of the name, ever thinks of using. True structural functionism, based on sound craftmanship, knowledgeably expressed, is bound, *ipso facto,* to produce a satisfactory "archi-

tectural effect" whether as a string course, a cornice and blocking course, Flemish bond, or a closed outer string and all that is left for the craftsman or the architect to do is to follow this lead and to emphasize rather than conceal those functional lines by mouldings or ornament. But were that the whole or chief contribution of an architect to the building-craft, he would merely be another of the world parasites, and should be exterminated as painlessly as possible along with other pests before ever we start out on "postwar planning problems,"for, in that case, books such as Mr. Deshpande's *Cheap and Healthy Homes for the Middle Classes, Modern Homes for India,* and *Build Your Own Home* would more than suffice.

Aspect, site, climatic conditions and local materials vary to such an infinite extent that no satisfactory solution can be found ready-made in any previous solution, even if of a somewhat similar problem, however successful it might have been for its own time and place, far less from any pre-conceived type-plan.

The architect's training, from beginning to end, is designed so as to equip him to tackle each individual problem as it arises. In facing such problems, suitability of material and skill in construction are faithful servants, but concentrated creative energy in design is the only successful master.

It is with such an outlook before him that I commend this little treatise on building construction to each of its readers and I sincerely trust that by its launching many may be carried far beyond its own narrow limits toward the realms of personal adventure, personal exploration, and personal research, for which so many opportunities cry out, if India is to take its rightful place in the world once again.

CLAUDE BATLEY

PREFACE

THE authors do not claim any originality in the compilation of this treatise, except perhaps in its treatment. They have made an attempt to deal with the various processes in Building Construction, from the foundation to the roof and finishing, in their proper sequential order, although while doing so the subjects of carpentry, reinforced concrete, and structural steelwork, which overlap almost every building operation, had to be isolated and treated separately.

While teaching the subject to the students of the Engineering College, Poona, the authors keenly felt the need of a suitable text-book primarily written for the conditions obtaining in this country. Those which were in use so far were essentially written for the conditions in the United Kingdom. The climatic conditions, social habits and the available materials, all of which influence building methods, are widely different in these countries. Furthermore, whereas most of the excavation work is done by machine in the United Kingdom, it is done by manual labour in India. All this inevitably makes the English text-books utterly unsuitable for this country. It is with a view to fulfilling this want that they have made this attempt.

It was the original intention of the authors to write the book to cover the syllabi of Indian Universities for the B. E. (Civil) course. But subsequently, it was thought desirable to widen its scope by including a few other subjects connected with modern building practice, so as to make the book more comprehensive. It is hoped that in addition to meeting the requirements of most of the professional examinations in Indian Universities, and Government and State Institutions, the practical nature of the treatise will render it useful also to Builders, House-owners, Estate Agents, Surveyors and Architects, as a book of reference.

Some of the illustrations have been repeated twice with a view to placing them close to the reference made to them in the text, instead of giving reference to a distant page, where the occasion occurred first.

They also express their indebtedness to Mr. Claude Batley, Professor of Architecture, J. J. School of Arts, Bombay, for agreeing to write the foreword.

R. S. DESHPANDE,

G. V. VARTAK.

PREFACE TO THE FIFTH EDITION

Opportunity has been taken once again to revise the text thoroughly. While doing so most of the illustrations have been redrawn to a larger scale. Besides the numerous small additions made here and there throughout the text, the chapter on Structural Steel Work has been enlarged by giving details of riveted and welded joints with examples of their designs worked out.

The chapter on Acoustics has been entirely rewritten with details of design of open air theatres, concert halls, radio broadcasting stations, and more particularly of cinema theatres with two examples of acoustic analysis solved.

The practical hints on the inspection of buildings under construction are sure to be appreciated by building engineers and supervising staff.

1st Jan. 1955. R. S. D.

PREFACE TO THE TENTH EDITION

This edition is revised in the following respects:

Since the Government of India, by an Act of Parliament, has made the use of the Metric system of weights and measurements compulsory from 1966, and optional during the three years prior to it, all numerical figures, calculations and illustrations have been converted to the C. G. S. units. Still, to avoid the possible confusion on the part of students during the transitional period, the old figures in F. P. S. units have been retained (except those in illustrations), and shown in brackets.

In the Chapter XXI on New Materials and Practices, *Epoxy Resins,* their composition and uses are briefly described.

I wish to express my thanks to Shri V. M. Deshpande, B. E., M. Sc. (Eng.), A. M. I. E., Lecturer, College of Engineering, Poona, for his valuable assistance in conversion to the Metric system.

Poona, 15th July 1964. R. S. D.

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BOOKS OF REFERENCE

A Treatise on Masonry Construction—I. O. Baker.

Building Construction—(Elementary and Advanced), 2 Vols.—C. F. Mitchell.

Practical Building Construction—J. P. Allen.

Building Construction, Parts I and II—Rivington.

Building Construction, Vols. I to IV—Newbold.

Roorkee Treatises—Parts II and VI.

Bombay P. W. D. Handbook.

M. E. S. Handbook, Parts I and II.

Building Design and Construction—E. J. Samuely and C. W. Hamann.

Building Construction for National Certificate—E. G. Warland.

Architectural Building Construction, Vols. I to III—Jaggard and Druary.

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Specification, Architects' and Builders' Journal, (Annual).

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Modern Framed Structures, 3 Vols.—Bryan and Turneaure.

Timber Development Series, Pamphlets, Forest Research Institute, Dehra Dun.

Acoustics—Alexander Wood.

Practical Acoustics for the Constructor—C. W. Glover.

Thermal Insulation of Structures— G. Yates Pitts.

Reinforced Concrete Designers' Handbook—C. E. Reynolds.

A Text-book of R. C. C. Design—R. S. Deshpande.

Architectural Forum, Philadelphia, U. S. A.

The Indian Concrete Journal.

ENGINEERING TEXT-BOOKS

1. MATERIALS OF CONSTRUCTION
by R. S. DESHPANDE

2. A TREATISE ON BUILDING CONSTRUCTION
by R. S. DESHPANDE & G. V. VARTAK

3. A TEXT-BOOK OF R. C. C. DESIGN
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13. IRRIGATION ENGINEERING
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14. ADVANCED CONSTRUCTION
by G. D. JOGLEKAR

15. BRIDGE ENGINEERING
by G. D. JOGLEKAR

FOUNDATIONS, EXCAVATING AND CONCRETING : 1

The term *Foundation* is applied to that part below the footings of a structure such as a wall, pier, stanchion, etc., artificially prepared, upon which the structure rests. It includes both the ground below and the artificial arrangement, such as concrete block, timber or steel grillage, piles, etc., upon which the base of the structure stands. The top of the artificial arrangement is called the *Foundation bed.*

The Purpose of Foundations is not, as is often confused, to support the weight of the structure, but (1) to distribute it over a relatively large area of substratum so as to prevent over-loading; (2) to load the substratum at a uniform rate so as to prevent unequal settlement; (3) to increase the stability of the structure to prevent it from overturning; and (4) incidentally to make a level surface, upon which to lay the courses of masonry.

Unequal settlement of foundations due to the movement of the sub-soil, first causes one or more unseemly vertical cracks in the structure, which if the cause still persists, widen, causing part of the structure to tilt on one side and ultimately to collapse.

Causes of Failure of Foundations : The principal causes are :

(a) Unequal settlement of the sub-soil.

(b) Unequal settlement of masonry due to the shrinkage and compressibility of mortar joints.

(c) Horizontal movement of earth adjoining the structure as in the case of clayey soils, particularly black cotton soil, usually assisted by other damaging influences.

(d) Withdrawal of moisture from the sub-soil underneath the foundations.

(e) Lateral pressure on the superstructure due either to the thrust of an arch, a member of a framed structure, inclined roof, or wind, etc., tending to overturn.

(f) Atmospheric action, sometimes assisted by the chemical reaction of the salts present in the soils.

(g) Lateral escape of sand or soft soil from underneath the foundations.

Of all these, the commonest cause is (a) unequal settlement of the sub-soil. Except rock and hard *muram* all other soils are liable to yield under pressure when the latter increases beyond certain limits. If the sinking were to occur at a uniform rate throughout and the relative positions of the different parts of the structure were to remain unaltered, it would not be of much consequence. But usually some part of the structure is higher than the rest, and the higher part is bound to impose greater weight on the foundation below it. Again, there may be concentrated loads on a few points only, such as columns, chimney bases, etc. It may also be possible, particularly in the case of buildings extending over a large area of ground, that the soil underneath may be of varying nature and may offer varying resistance to loads on foundations. Under these circumstances, unless special precautions are taken, unequal settlement is bound to occur.

To counteract the tendency of unequal settlement, the following principles are observed when designing foundations:

(1) No part of the foundation should, under any combination of loading, be stressed beyond the safe bearing power of the particular soil below it. Thus the entire base of the structure is either allowed to *float* on the foundations, or, if a reasonable subsidence is allowed, the latter should be even all over the area.

(2) To make the axis of the load, i.e., the vertical line passing through the centre of gravity of the weight, coincide with the centre of the area of the foundation. If this does not take place the ground will sink under the portion which is pressed most causing the part of the structure above it to assume an inclined position, which ultimately results in producing vertical cracks.

To err on the safe side, the axis of the load should strike a little *inside* of the centre of the area of the base, to make sure that it does not fall *outside*. The inward tilting of the wall is made impossible by the beams and cross walls across, on the inner side.

(3) No material which is likely to disintegrate or deteriorate from any cause so as to lose strength and resistance to ex-

ternal influences, should go into the foundations and that part of the structure covered underground and hidden from view.

TABLE No. 1

SAFE PERMISSIBLE LOADS ON DIFFERENT SOILS

	Description of Soil	Safe Load in Tonnes/m.^{2}
1.	Soft, wet, pasty or muddy clay, and marshy clay ..	2 to 3.5
2.	Alluvial deposits of moderate depths in river-beds ..	2 to 3.75
3.	Diluvial clay in beds of rivers	3.75 to 11.00
4.	Black cotton soil	5 to 7.5
5.	Alluvial earth, loams, sandy loams (clay and 40 to 70 per cent of sand) and clay loams (clay and about 30 per cent of sand)	7.5 to 16
6.	Moist clay	11 to 18
7.	Compact clay, nearly dry	22 to 27
8.	Solid clay mixed with very fine sand	44
9.	Dry, compact clay of considerable thickness	33 to 55
10.	Loose sand in shifting river-beds, the safe load increasing with depth	16 to 27
11.	Silted sand of uniform and firm character in a river-bed secure from scour and at depths below 8m. (25 ft.)	38 to 44
12.	Compact sand	22 to 33
13.	Compact sand, prevented from spreading	55 to 82
14.	Sandy gravel, or "kunkur"	22 to 33
15.	Do. but compact, dry and prevented from spreading	44 to 65
16.	Very firm, compact sand at a depth not less than 20′ and compact sandy gravel	65 to 75
17.	Firm shale, protected from weather and clean gravel	65 to 85
18.	Red earth	33
19.	"Muram"	44
20.	Compact gravel	75 to 95
21.	Rock	from laterite 25 tonnes to granite 275 tonnes and upwards.

The load coming on foundations consists of: (1) *Dead Load* or the load of the building itself; (2) *Live Load*, or the

moveable load on floors, and the load of snow on the roof in the regions where snow falls, and (3) *Wind Load.*

Dead Load is found by calculating the weight of the cubical contents of the different materials employed in the structure. Concentrated loads, such as those below the ends of beams, are spread out radially, and so, if the vertical distance between the point of application of the load and the foundation is considerable, as is usually the case, the loads may be assumed as uniformly distributed over the entire area of the base.

TABLE No. 2

SAFE COMPRESSION STRESSES IN MASONRY

Kind of Masonry or Concrete	Compression Stress Tonnes/m.^{2}
Ashlar Masonry ..	170
Rubble Masonry in Lime Mortar ..	85
I and II Class Brick Masonry in 1 : 4 Cement Mortar ..	130
I and II Class Brick Masonry in Lime Mortar ..	65
III Class Brick in Lime Masonry ..	44
Cement Concrete 1 : 2 : 4 ..	330
,, ,, 1 : 3 : 6 ..	220
,, ,, 1 : 4 : 8 ..	110
Lime Concrete ..	75

TABLE No. 3

WEIGHTS OF VARIOUS SUBSTANCES

[These weights are for solid materials except where otherwise stated. Allowance must be made for the weights of broken materials varying with the percentage of voids. Green timbers weigh ⅕ to ½ more than dry.]

	kg./m.^{3}		kg./m.^{3}
Aluminium	2600	Asphalt	2300
American ash	610	Ballast and sand,	
Ashes (loose)	650	damp, loose	1450 to 1675

	kg./m.³
Ballast and sand, well shaken	1575 to 1875
Ballast and sand, thoroughly wet	1920 to 2240
Bell metal	8040
Bitumen	1400
Brass, cast	8060
Brick, best pressed	2400
Brick, fire	2200
Brick, common hard	2000
Brick, soft, inferior	1600
Brickwork, pressed brick in cement	2250
Brickwork, ordinary	1900
Cement, loose from sacks	1200 to 1450
Chalk	2200
Clay, in lump, loose ..	1100
Clay, solid	1920
Coal, solid	1300
Coal, broken, loose ..	830
Coke, loose	480
Concrete (ballast or gravel)	2240
Concrete (breeze) ..	1440
Concrete (brick) ..	2200
Concrete (reinforced)	2400
Copper, cast	8600
Copper, sheet	8810
Earth, common, loam, dry loose	1220
Earth, common, loam, dry moderately rammed ..	1520
Earth, compacted	2200
Earth, as a soft, flowing mud	1725
Elm, dry	560
Flint	2500
Glass, common window	2525
Glass (sheet and plate)	2500-2800

	kg./m.³
Grain	775
Granite	2625
Gravel, common, loose ..	1750
Gun-metal	8450
Hay	75
Hay, pressed	125
Hemlock, dry	400
Ice	900
India rubber	950
Iron, cast	4000
Iron, wrought	7700
Ironstone	2150
Iron ore	3700
Lead	11375
Lime, slaked	400-600
Limestone	2650
Limestone, loose broken	1550
Macadam	2400
Marble	2525
Masonry, dressed granite or limestone	2650
Masonry, dressed rubble set in mortar ..	2475
Masonry, dressed rubble, dry	2200
Masonry, dressed sandstone	2300
Mortar, hardened ..	1650
Mud, dry, close	1250-1750
Mud, wet, fluid, maximum	1925
Oak, dry	800
Oil, (fuel, lubricating, and linseed)	900
Petrol	675
Pumice stone	925
Pine, white, dry	400
Pine, yellow	540-720
Pine, pitch	500
Pitch	1220
Plaster of Paris, cast ..	1275
Plaster cement	2075
Plaster lime	1925

	kg./m.³		kg./m.³
Quartz	2645	Spar, calcareous ..	2750
Quicklime, ground, loose, or in small lumps ..	850	Spelter or zinc	7050
Quicklime, ground, loose thoroughly shaken ..	1200	Spruce, dry	400
Red lead	8925	Steel	7800
Roof (see sq. m. measurements below)		Stone, Basalt	2600
Salt, loose	800-1025	Stone, Granite	2625
Salt, solid	2125	Stone, Lime	2400
Salt, dry, loose	1400-1700	Stone, Marble	2475
Sand, pure quartz, perfectly dry, slightly shaken	1400-1690	Stone, Sandstone ..	2675
Sand, natural, dry, maximum	1875	Stone, Traprock ..	2750
Sand, thoroughly wet, saturated	1900-1925	Tallow	950
Shale	2600	Tar	1225
Slag (Broken) ..	1450	Terra-cotta	1800
Slate	2800	Tile	1800
Snow, freshly fallen	75-100	Timber (Constructional)	675
Snow, moistened and compacted by rain ..	250-800	Tin	6500
		Water, pure, at 39.2° F., or 4°C. (for basis of determining specific gravity) ..	1000
		Water, rain, at 60° F. ..	998
		Water, sea (salt) ..	1025
		Zinc	7015

kg./m.² Measurements

Doors with frames	—	—	39 kg./m.²
Roof asbestos cement sheet	—	—	34 ,,
,, Eternit sheet	—	—	24 ,,
,, C. G. I. sheet with frame	—	—	10 ,,
,, Allahabad tiles (single)	—	—	83 ,,
,, Allahabad tiles (double)	—	—	160 ,,
,, Country tiles (single)	—	—	70 ,,
,, Country tiles (double)	—	—	115 ,,
,, Mangalore tiles	—	—	50 ,,
,, 6″ Thatch and frame	—	—	30 ,,
Timber trusses and purlins	—	—	12 ,,

Live Load, or moveable load, on floors depends upon the nature of the building. Its equivalent dead loads are taken for the purpose of design, as given in Table No. 4 as recommended by the *Indian Code of Practice* (1953).

TABLE No. 4
MINIMUM AND ALTERNATIVE MINIMUM IMPOSED LOADS

Loading class No.	Type of floor	Minimum live load per unit area (kg/m²)	Alternative minimum live load: For slabs, uniformly distributed over span (kg)	Alternative minimum live load: For beams uniformly distributed over span (kg)
200	Floors in dwelling houses, tenements, hospital wards, bed-rooms and private sitting rooms in hostels, and dormitories.	200	500	1200
250	Office floors, other than entrance halls, floors of light work-rooms.	250-400*	625-1000	1500-2400
300	Floors of banking halls, office entrance halls and office floors below entrance halls and reading rooms.	300	750	1800
400	Shop floors used for the display and sale of merchandise; work-rooms generally; floors of class rooms in schools, garages for vehicles not exceeding 2.50 tonnes gross weight, places of assembly with fixed seating, churches, chapels, restaurants, circulation space in machinery halls, power stations, etc. where not occupied by plant or equipment.	400	1000	2400
500	Floors of ware-houses, workshops, factories and other buildings or parts of building of similar category for light-weight loads, office floors for storage and filing purposes, places of assembly without fixed seating (Public rooms in hotels, dance halls, waiting halls, etc.)	500	1250	3000
750	Floors of ware-houses, workshops, factories and other buildings or parts of buildings of similar category for medium weight loads, floors of garages for vehicles not exceeding 4.064 tonnes gross weight.	750	For garage floors only 1.5 times the maximum wheel load, but not less than 900 kg considered to be distributed over a floor area of 0.750 sq. m.	

* The lower value of 250 kg/m² should be taken where separate storage facilities are provided, and the higher value of 400 kg/m² where such provisions are lacking.

TABLE No. 4 (Contd.)
MINIMUM AND ALTERNATIVE MINIMUM IMPOSED LOADS

Loading class No.	Type of floor	Minimum live load per unit area (kg/m²)	Alternative minimum live load*: For slabs uniformly distributed over span (kg)	Alternative minimum live load*: For beams uniformly distributed over span (kg)
1000	Floors of warehouses, workshops, factories, and other buildings of similar category for heavy-weight loads, floors of book stores, roofs and pavement lights over basements projecting under the public footpath.	1000		
	Stairs, corridors, landings and balconies not liable to overcrowding			
	For class 200 loading	300		
	For all other classes	500		
	Balconies liable to overcrowding	500		

* Minimum load for slabs becomes operative at spans of less than 2.5 m. Minimum load for beams becomes operative on areas less than 60 m.² Beams, ribs and joists spaced at not more than one m. centres may be calculated for slab loading.

TABLE No. 5

REDUCTION IN FLOOR LOADS ON COLUMNS, WALLS, ETC.

Reduction in the assumed total live loads on floors may be made in designing columns, walls, piers, their supports and foundations and such reductions should be as follows :

Storey	Reduction, per cent of the live load
First storey below the topmost storey	10
Second storey below the topmost storey	20
Third storey below the topmost storey	30
Fourth storey below the topmost storey	40
Fifth storey and each lower storey below the topmost storey	50

Wind Pressure :—When the height of a building is less than three times its effective width, and further when adequate stiffening is made by cross walls and floor slabs, wind pressure may be neglected.

In the design of roofs, a minimum pressure of 50 kg./m.^{2} (10 lb./ft.^{2}) on the windward side, and a suction (minus pressure) of 50 kg./m.^{2} (10 lb./ft.^{2}) on the leeward side should be allowed as a general rule.

Wind Pressures on Vertical Surfaces to be allowed are given in the following table :

TABLE No. 6

WIND VELOCITIES AND BASIC WIND PRESSURES

H (m)	v (km per hour)	p (kg/sq m)
5	109	76
10	120	92
15	127	104
20	132	112
25	137	120
30	140	126
40	146	137
50	151	146
60	155	154
80	162	167
100	167	178
125	172	190
150	177	200

where H = the height in meters of exposed surface above the mean retarding surface.

v = horizontal velocity of wind in kmph at height H, and

p = total horizontal effect of wind in kg/sq m which is made up of pressure on the windward surface and suction on the leeward surface.

Note 1 :—The above pressures should be doubled for all structures in the following areas :—

(a) Areas, S. W. and W. of a line passing through but excluding Hyderabad (Sind), Baroda, Ratnagiri and (b) Areas within 50 miles of the coast line between Masulipatam and Akyab.

Note 2 :—For structures inland of a line through and including Gwalior. Chittorgarh, Aurangabad, Tirupur, Madura, Trichinopoly, Jalarpet, Cuddappah, Dornakal, Jharsuguda and Allahabad, the above pressures may be halved.

TABLE No. 7

WIND PRESSURES ON ROOFS NORMAL TO EAVES

Roof slope	Windward slope of pitched roof (or half of flat roof)	Leeward surface
0°	- 1.0	
$22\frac{1}{2}$°	- 0.25	- 0.5
30°	0	
45°	+0.25	

The maximum wind pressure is alternatively taken as 3.75 kg./m.^{2}(0.75 lb./ft.^{2}) per degree of inclination of roof to the horizontal. Thus for normal roof slope at 1 to 2 (26° 34′) it is 100 kg./m.^{2} (20 lb./ft.^{2}).

To revert to the causes of failure of foundations :

(*b*) *Unequal Settlement of Masonry* due to shrinkage and compressibility of mortar joints.

The mortar used in joints shrinks and is also compressible particularly if considerable load is brought on it before it has set and hardened. The following precautions should be taken against this :

(*i*) Use as stiff mortar as possible consistent with workability.

(*ii*) The progress of work in raising masonry should be

kept low. As a rule not more than three feet of wall should be constructed in a single day, if lime mortar is used and not more than five feet in the case of cement mortar.

(*iii*) The whole masonry in any structure should be carried up at one uniform level throughout. If one part is raised more than the other, the greater height of the part raised will exert more pressure on the mortar in the joints and cause subsidence.

(*c*) *Horizontal Movement of Earth* adjoining the structure is liable to occur when the soil is very clayey, i. e. of such a nature as excessively swells when wet, and excessively shrinks when dry again. Black cotton soil is typical in this respect. The horizontal movement of the layers of the soil along the rough sides of the concrete and underground masonry causes tensile stresses in the latter. When wet, such soils become very soft and lose their bearing power considerably. The following remedies have been tried and proved useful in the case of ordinary soils, but in the case of black cotton soil they are not successful :

(*i*) To reduce the intensity of pressure on the soil, so as not to exceed the limit of 5.0 tonnes/m.^{2} ($\frac{1}{2}$ ton/ft.^{2}).

(*ii*) To excavate foundation trenches to such a depth as cracks will not reach.

(*iii*) To interpose a layer of sand, *muram*, or some other loose material between the concrete or masonry in the foundation and the clayey soil so as to prevent contact between the two.

Black cotton soil is very treacherous. In spite of the above precautions a building on black cotton soil may stand quite sound for ten or fifteen years and then suddenly develop cracks without warning. The only perfectly satisfactory course is either to provide R. C. C. foundations, or drive piles up to rock or hard pan.

(*d*) *Withdrawal of moisture* from the sub-soil. This is particularly likely to happen in foundations in damp soils overlying a layer of porous material like sand or gravel. In a year of drought when the sub-soil water level sinks very low, the soil below the foundation may lose its moisture and shrink, tending to cause a crack in the structure by unequal settlement. The same thing takes place if an opening for draining of water from the sub-soil is made either by a well sunk, or deep sewer constructed, or a deep railway cutting excavated nearby.

(e) *Lateral Pressure on the Superstructure* : The horizontal component of the thrust due to an arch at the end of a wall or to a pitched roof, wind, etc., tends to overturn the wall, and if the latter has no sufficiently wide area of base, it may tilt. When this happens the whole weight of the wall is concentrated at, or near the edge under pressure tending to crush the material and cause the foundation to settle unevenly.

Widening the base of the structure so as to increase its stability and reducing the thrust by suitable means are the precautionary measures.

(f) *Atmospheric Action* :—There are a few soils, which, if rain water soaks into them, lose their cohesion. Oftentimes, the foundations are exposed by the erosion of the ground by rain water running close to them. Variations of temperature and frost also affect the layers up to a few feet below the ground level. Salts, particularly those present in sewage and animal dung lying scattered on the ground surface, are dissolved and carried by rain water to the ground close to the foundations, and when absorbed by the sub-soil, react chemically on the lime and bricks in the foundation and cause them to disintegrate and fall to powder.

The precautionary measures are : (1) To excavate the foundation deep enough to go beyond the effects of the atmospheric action. A minimum depth of three feet is prescribed for ordinary soils. (2) To use stone and lime or cement mortar, as far as possible, below the ground level and also up to the plinth, when such soils are met with. Where stone is scarce, overburnt bricks may be used. (3) After the masonry in foundations rises above ground, the sides of the trenches should be well filled and consolidated, and a good slope away from the walls given to the ground surface, so that rain water flows rapidly away from the masonry.

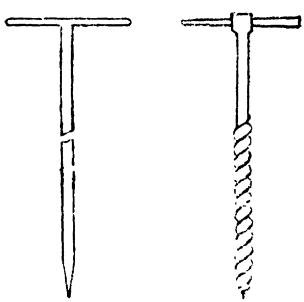
(g) *Lateral Escape of Material* : When a foundation trench has a very small margin of ground on one side, as for instance, on or close to a sloping river bank, or a deep cutting, or a well, so as to find an outlet either by direct exposure or through holes burrowed by animals like rats, bandicoots, crabs, etc., the layer of soft earth, if any, or of sand, either natural, or purposely fill-

ed into the trench, may ooze or be squeezed out under the pressure, forming a hollow below the foundation, which might sink and break in consequence. Either such positions should be avoided, or the trenches should be confined by driving sheet piles.

Examination of the Ground: The usual methods adopted are: (a) Inspection, (b) Probing, (c) Boring, and (d) Test-pits.

(a) *Inspection* of site is naturally the first step. From an examination of the surface of the ground and the immediate vicinity, particularly the strata exposed to view in the banks of *nallas*, or sides of pits, or unbuilt wells, it is possible to gather some valuable information regarding the nature of the substrata and their depth.

(b) *Probing* is confined to shallow foundations in soft strata like clay, sand, gravel, etc. A steel bar of about 32 mm. ($1\frac{1}{4}$ in.) diameter, pointed at one end, and of suitable length (Fig. 1) according to the depth of the soft or loose material, is forced vertically into the ground and worked like a jumper until a hard substratum is tapped. A hammer may be used with advantage for driving the bar down. It may be withdrawn from time to time and the point examined for traces of the material met with, sticking to it. The nature of the final hard stratum encountered may be recognized by the feel, sound, and the particles sticking to the point, and the depth of the bore measured.



Figs. 1 & 2

For testing shallow foundations in clay or sand an instrument called 'wood auger' is often very useful. It is just like the auger for drilling holes in wood, but a little stronger (Fig. 2).

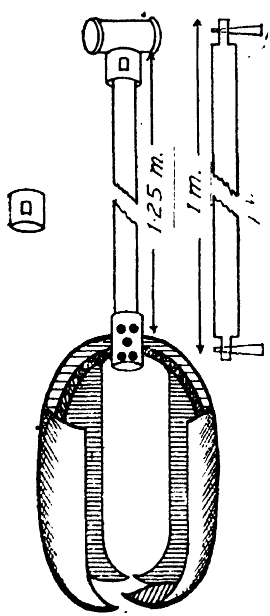
(c) *Boring*: For testing foundations of ordinary buildings, a post-hole earth auger shown in Figs. 3 to 5 is a very handy and useful instrument. The auger is held vertically and is rotated by applying leverage while being pressed down at the same time. It should be withdrawn, say, at every foot of the depth penetrated and the samples, which it brings up, examined. The instrument is very useful in common soils except those of loose mate-

rials like sand or gravel. It cannot be used also when any hard stratum like *muram*, *kunkur*, or rock is met with. In ordinary soils, two men can easily drill a bore 3 m. (10 ft.) deep in a day.

For the foundations of very heavy structures, boring machines driven by power may be used. The appliances used are of two types :

(1) *Percussion Boring Machine* in which the strata of hard material like rock are penetrated by a series of blows delivered from heavy cutting tools, so that the material is broken up and pulverised. Water is poured into the bore and the paste formed is sucked and lifted up. The powder, when dry, can be examined and the nature of the rock determined. The percussion boring machine is useful only in hard material like rock.

(2) *Core Drilling Machine*: This is a rotatory auger of hollow tubular section which can be used both for soft material, like clay, sand, etc., or hard material like *muram* or rock. In soft or loose material a steel pipe is first driven by blows of a hammer, and the material inside it is drilled through and brought to the surface through the hollow drill. In rock a different bit is used to penetrate it by the abrasive action of the rotating cutting tool. The hollow tubular section of the drill has the advantage that it brings solid cores of the rock to the surface.



Figs. 3—5 :
Post-hole auger, with lengthening bar and linking head.

(d) *Test-pits*: These are suitable for the examination of comparatively shallow foundations, for determining the difficulty or ease of excavation, the necessity or otherwise of shoring, etc. but afford, within their limits, the most satisfactory

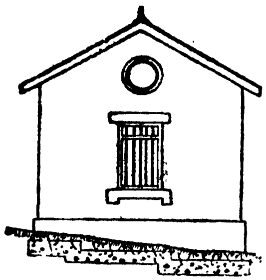


Fig. 43 : Stepped or benched foundation.

bridges, sea-walls, etc. which may be under water. They are rarely used for buildings. Hence they are not treated here.

Stepped Foundations : When the ground is sloping, the foundation trenches of walls are stepped or benched, as shown in Fig. 43 to prevent waste of labour and material. This also results in keeping the depth of walls as nearly uniform as possible. Care should be taken to extend the lower layer of concrete under the upper one for a distance equal to the thickness of the concrete, otherwise a weak spot may be formed at the junction of the step.

Illustrative Examples on Design of Eccentric Foundations :

Example 1 : Find out the maximum and minimum pressures on the soil at the base of an independent footing below a concrete block 2.5 m. × 2 m. × 75 cm. thick. The load on the block which is applied at 15 cm. on one side of the centre along the longitudinal axis is 120 tonnes.

Solution : Weight of the Concrete Block

$= 2{\cdot}5 \times 2 \times 0{\cdot}75 \times 2240$

$= 8{\cdot}44$ tonnes acting at the centre.

Total Load $= 120 + 8{\cdot}44 = 128{\cdot}44$ tonnes.

Taking moments about the edge of the short side on the side of the point of application of the load.

$8{\cdot}44 \times 1{\cdot}25 + 120 \times 1{\cdot}10 = 142{\cdot}55$ m. tonnes

Position of the centroid $= \dfrac{142{\cdot}55}{128{\cdot}44} = 1{\cdot}11$ m.

Eccentricity $e = (1{\cdot}25 - 1{\cdot}11) = 0{\cdot}14$ m.

$\therefore \dfrac{l}{6} = \dfrac{2{\cdot}5}{6} = 0{\cdot}417$, $0{\cdot}14$ is less than $\dfrac{l}{6}$

$\therefore \; k = \left(1 \pm \dfrac{6e}{l}\right) = \left(1 \pm \dfrac{6 \times 0{\cdot}14}{2{\cdot}5}\right)$

$= 1{\cdot}336$ or $0{\cdot}664$

$$\text{Max. } p_1 = \frac{k\Sigma W}{l \times b} = \frac{1{\cdot}336 \times 128{\cdot}44}{2 \times 2{\cdot}5}$$
$$= 34{\cdot}32 \text{ tonnes/m.}^2$$

$$\text{Min. } p_2 = \frac{0{\cdot}664 \times 128{\cdot}44}{2{\cdot}5 \times 2}$$
$$= 17{\cdot}06 \text{ tonnes/m.}^2$$

Example 2 : Find out the maximum pressure on the base in the above example, if the point of application of the load is 0.5 m. away from the centre on the same side as above.

Solution : Taking moments as before

$$8{\cdot}44 \times 1{\cdot}25 + 120 \times 0{\cdot}75 = 100{\cdot}55 \text{ m. tonnes}$$

$$\text{Position of the centroid} = \frac{100{\cdot}55}{128{\cdot}44} = 0{\cdot}78 \text{ m.}$$

$$\text{Eccentricity } e = (1{\cdot}25 - 0{\cdot}78) = 0{\cdot}47 \text{ m.}$$

This is greater than $\frac{l}{6}$ or $\frac{2.5}{6} = 0{\cdot}417$ m.

$$\therefore \; k = \frac{l}{3\left(1 - \frac{2e}{l}\right)} = \left\{\frac{1{\cdot}25}{\left(1 - \frac{2 \times 0{\cdot}47}{2{\cdot}5}\right)}\right\} = 2$$

$$\text{Max. } p_1 = \frac{kW}{l \times b} = \frac{2 \times 128{\cdot}44}{2{\cdot}5 \times 2} = 51{\cdot}38 \text{ tonnes/m.}^2$$

Example 3 : A wall 20 m. long and 1.5 m. wide at the base of its footing carries five concentrated loads at the following distances from the left hand side : 20 tonnes at 3, 30 tonnes at 8, 40 tonnes at 9, 48 tonnes at 16, and 12 tonnes at 18 m. Find out the maximum and minimum pressures.

Total loads $= 20 + 30 + 40 + 48 + 12 = 150$ tonnes

Moments about the left hand edge

$$= 20 \times 3 + 30 \times 8 + 40 \times 9 + 48 \times 16 + 12 \times 18$$
$$= 60 + 240 + 360 + 768 + 216$$
$$= 1644 \text{ m. tonnes}$$

$$\text{Position of centroid} = \frac{1644}{150} = 10{\cdot}96 \text{ m. from left hand edge}$$

$$\text{Eccentricity } e = 10{\cdot}96 - 10 = 0{\cdot}96 \text{ m.}$$

TABLE No. 9
ANGLES OF REPOSE AND WEIGHTS OF DIFFERENT SOILS

Description of Soil	Angle of Repose in Degrees	Weight in kg./m.^{3}
Very wet earth, wet clay	15	1440
Wet sand, gravel with sand	25	1600
Dry earth, dry clay, dry sand	30	1680
Moist earth, shingle	40	1520
Clean gravel	45	1700

TABLE No. 10

Angle of Repose in Degrees or Slope $\frac{H}{V}$	Value of $\left(\frac{1 - \sin\theta}{1 + \sin\theta}\right)^2$
15 (3.2 to 1)	0.346
20 (2.7 to 1)	0.245
30 (1.7 to 1)	0.111
45 (1 to 1)	0.0295
33°41′ (1½ to 1)	0.0804
26°34′ (2 to 1)	0.1444
18°26′ (3 to 1)	0.2894
14°29′ (4 to 1)	0.3707

When the foundation is in solid rock, concrete is required for objects (2) and (3) only. Hence just a thin layer of it, to
The block should project at least 10 cm. (4 in.) on either side
make the surface level, may suffice.
of the lowermost course of the footing. This projection is treated as a cantilever beam with a vertical upward pressure on the projecting part equal to the reaction of the bearing soil.

Considering one meter length of the block,

If d = depth of the block in cm.,

j = projection in m.,

p = load on foundation in kg./m.^{2} which is also the the reaction of the bearing soil.

m = safe modulus of rupture of the concrete block in kg./cm.^{2}

$$\text{B.M.} = \frac{pj^2}{2} \text{ m. kg.}$$

$$= \text{resisting moment for equilibrium}$$

Resisting moment of the concrete block $= \dfrac{md^2}{6}$ m. kg.

$$\therefore \quad \frac{pj^2}{2} = \frac{md^2}{6}$$

Solving this, we get

$$d^2 = \frac{3\,pj^2}{m}$$

From this, d can be calculated. The values of m are given in the sub-joined table.

TABLE No. 11

MODULUS OF RUPTURE OF CONCRETE kg./cm.^{2}

Material	m = Modulus of Rupture
Lime concrete (1 mortar to 3 stone metal)	1·55
Cement Concrete (1 : 4 : 8)	2·46
„ (1 : 3 : 6)	3·52
„ (1 : 2 : 4)	5·27

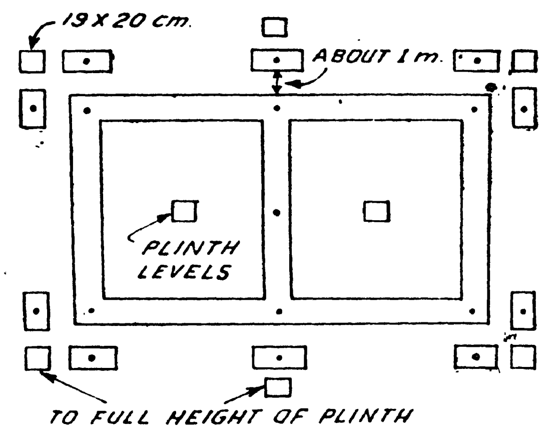
Illustrative Examples in Design of Foundations

Example 1 : Design the foundation of a domestic building, three storeys high, with a roof of Mangalore tiles (2 to 1 slope), on 20 mm. Moulmein teak ceiling. Height of the underside of the roof above the ground is 12 m. The soil consists of moist clay mixed with sand, with an angle of repose 33° 41′ (1½ to 1), with a safe bearing power of 16 tonnes per sq. m. and weighs 1600 kg./m.^{3}. The walls are 1½ brick thick in lime

third for the hypotenuse, are very useful in doing it with mathematical accuracy. On important works a theodolite should be used.

For systematic setting out, platforms of brickwork plastered with lime on top, about 15 cm. (6 in.) wider than the proposed foundation trenches and at least 60 cm. (two ft.) clear of their outer edges, should be constructed as shown in Fig. 45. If the ground be sloping, the platform at the higher level should be of one course of stretchers plastered on top and the others of heights to make an approximately level plane with its top surface. When the lines are finally correctly set out and checked by the diagonal measurements the strings stretched on the centre points should be pressed by means of a mason's trowel on the top of the platforms to leave their marks on the wet plastered surface. The outer lines of the trenches also may be similarly marked on the platforms. These remain intact for a fairly long time, and are useful for checking the measurements at any time.

Fig. 45 :
Layout of the centre line of foundation of the exterior walls of a building.



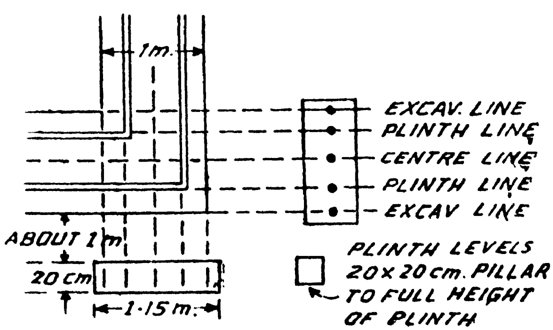


Fig. 46 :
Shows a corner of a building to illustrate how marks are made on plaster on the top of pillars at corners.

Before commencing excavation, strings should be stretched along the marks of the lines of trenches, and lime powder may be used for marking them on the ground. In windy weather or when the excavation is not to start immediately, the lines may be marked by the pointed end of a pick axe.

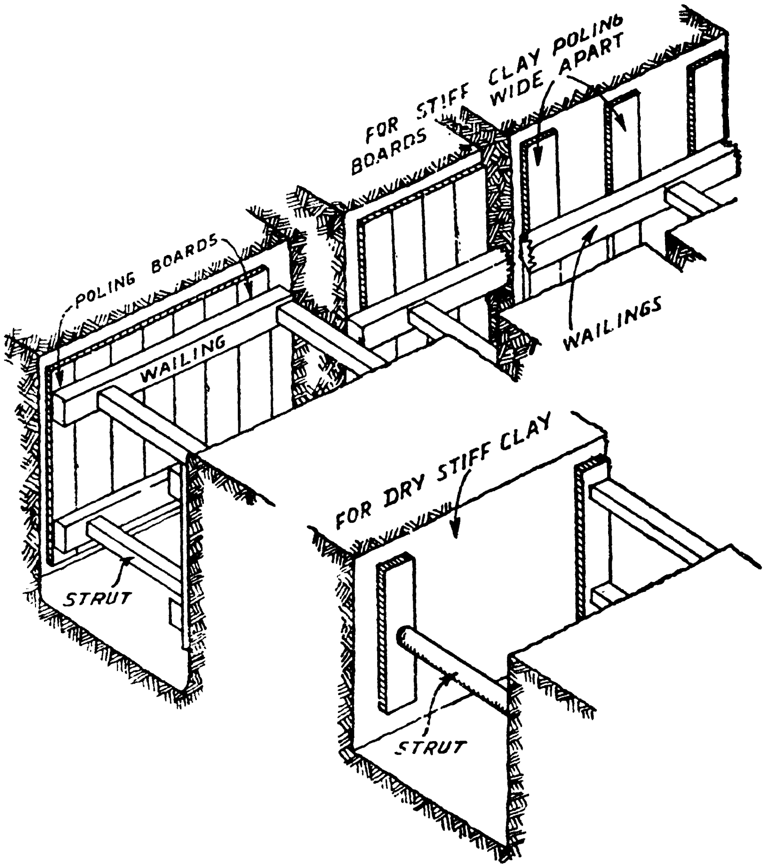


Fig. 47 :
Poling boards close together and double struts between walings for loose earth.
Fig. 48 :
For medium clay single struts.
Fig. 49 :
For stiff clay poling boards wide apart.
Fig. 50 :
For dry clay single struts between poling boards with no walings.

When the plinth level is fixed, a number of brick* pillars 20 cm. × 20 cm. (9 in. × 9 in.) of the full height of the plinth as shown in the figures, should be constructed, one at each corner, and if the building is extensive, one in front of the end of each inner wall. The masonry work of the foundation or plinth can be checked at any time, by stretching strings along the lines marked in the plaster on top of these pillars, thus saving the time and labour in checking with a spirit level.

Excavation for Foundations : The trenches for foundation of walls or piers should be excavated to the exact width, length and depth, as shown on the drawing. The widths shown on the drawing are those at the bottom. If the soil is firm and the depth is not excessive, the sides of the excavation may remain vertical without support for a few days till concreting is done and masonry is raised to the ground level. But when the excavation is deep or the sides are not of firm soil, the sides must either be suitably sloped, or if left vertical, they must be supported by some arrangement of boarding, called timbering or *shoring*. The latter is necessary when the excavation adjoins a property line. Usually, when the depth of excavation exceeds 6 ft., shoring the sides is more economical. But that also depends upon the quality of the material to be excavated. If it is running sand, marsh, or morass, shoring will have to be resorted to almost from the surface of the ground.

When the soil is of a clayey nature, which though firm, is likely to develop vertical cracks in the sides by exposure to the sun and wind, and slip, simple *poling boards* of size 20 cm. × 4 cm. (8 in. × 1½ in. to 2 in.) are placed vertically in pairs, one on each side of the trench, and strutted apart by stout pieces of bullies about 10 cm. (4 in.) in diameter called struts, as shown in Fig. 50. But when the soil is looser, the poling boards must be placed closer together perpendicularly with walings 25 cm. × 8 cm. (10 in. × 3 in.) held horizontally against them on the inner side and strutted as before (see Fig. 49) at intervals of about one meter (3 ft.).

For facility of lifting and removing the excavated material from the bottom of a deep trench, as well as for that of filling con-

* The Indian Standard Institution (I.S.I.) has tentatively taken the standard size of brick as 20 cm. × 10 cm. × 15 cm. (nominal). The same has been adopted in this volume.

crete subsequently when the trench is ready for it, platforms are formed at convenient levels by nailing planks on the top of some of the struts as shown in the vertical section of a trench in Fig. 51 in which some concrete is shown to have been laid at the bottom.

In still loose soils, in which the sides of the trenches cannot stand unsupported for a height greater than a few cm. (inches), the boards used immediately against the sides of the trenches are placed horizontally. These boards are known as *sheeting*. In such a case, the excavation is carried to a depth of 20 to 25 cm. (9 in.) and is immediately supported by planks placed against the opposite sides and held in position by struts. After this, the next 20 to 25 cm. (9″) are excavated, and the sides are similarly protected. When five or six planks are thus inserted on each side, vertical planks are added, and some of the struts are dispensed with.

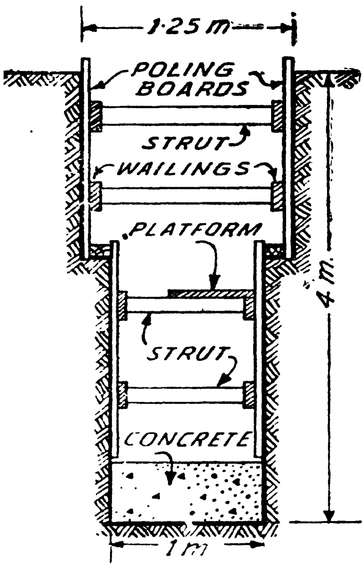


Fig. 51 :
Vertical section of trench, showing how the sides are protected by shoring.

In very loose soil, like running sand, the method followed is different. Long planks, called *Runners* about 8 cm. (3″) thick and 18 to 22 cm. (7″ to 9″) wide, pointed and sometimes shod with iron at one end, are placed behind the walings instead of the poling boards. In this case the walings and struts are required to be of substantial section, as they have to withstand greater pressure.

As the work proceeds, the runners are constantly driven in, care being taken to see that they are always about 30 cm. (a foot) or so in the ground below the bottom of the trench.

To revert to the subject of excavation, the bottom of the trenches should be at one uniform level throughout, unless the ground is sloping, when it is stepped for economy. Even then the top surface of every stepped length should be horizontal. If loose pockets are met with, they should be cut square and filled with concrete, or if very deep, they may be carefully arched over.

In no case should the excavated material be allowed to be deposited within 1·5 m. (5 ft.) from the outer edge of the trenches, and no material should be allowed to be stacked or heaped in the spaces between the trenches.

If it be soft rock, the bottom of the trenches should be struck with an iron bar or a hammer, and if in any part it sounds hollow, that part should be excavated and filled with concrete.

Soils which are soft and permeable can be made hard and water-tight by *cementation*, by which they are impregnated with cement grout or certain chemicals. Bores, both vertical and inclined, are first drilled by a machine, the tool is withdrawn and a perforated pipe inserted, through which cement grout is forced under great pressure. But, as it is very costly, it is used for water-tightening dams and rarely for foundations of ordinary buildings.

If the surface at the bottom of a trench be of rock which is sloping, it should be made level by chiselling. If the slope is considerable and is in the direction of the longitudinal axis of the trench, it should be cut and divided into horizontal terraces at different levels.

Filling Concrete in Foundation Trenches: Unless specifically desired, lime concrete is generally used for the sake of economy. In situations exposed to water, the lime used for concrete should be hydraulic, or if it is fat, it should be artificially made hydraulic by mixing *surkhi* with it. The standard proportions are 3 parts of aggregate (broken stone, gravel and sand) and one of lime mortar consisting of 1 : 2 : 1 or 1 : 3 : 0 of lime : sand : surkhi.

If concrete is relatively cheaper than rubble masonry or brickwork, it may be filled up to 15 cm. (6 in.) below ground level in the case of external walls to prevent any chance of its being exposed to view in the event of possible erosion of surface soil, and up to ground level for internal walls.

If the concrete is massive, i.e. more than, say 1 m. (3 ft.) wide and deep, what is called "plum-concrete" is more economical and at least equally strong. For this, first lay a 10 to 15 cm. (4 to 6 in.) layer of concrete and ram it well. Then on the top of this lay some two inches of concrete and before it is rammed, place big, clean, hard, flawless stones with their flat surface at

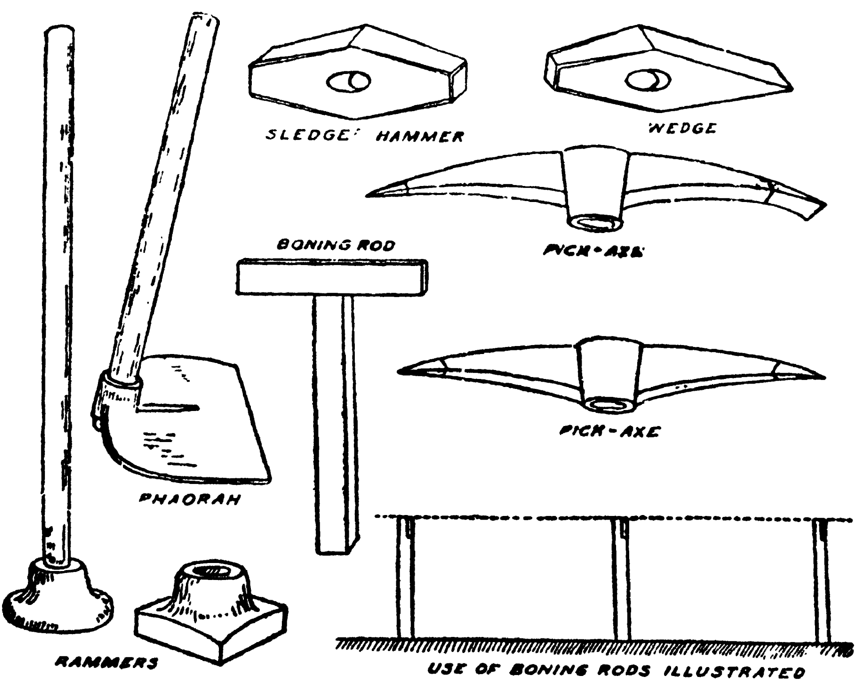
bottom, leaving at least 15 cm. (6 in.) space between them. Their vertical height should not exceed half the depth of the concrete in the trench. Level the top surface with concrete and ram it hard.

Sometimes 1 : 4 : 8 cement concrete is cheaper, and certainly more convenient than lime concrete.

In the case of concrete with ordinary cement, the ramming should be completed within half an hour after laying.

The concrete should be thoroughly mixed on a clean, impervious platform with water just enough to make it sloppy, and should be laid at the bottom (and not thrown from the top, which causes the aggregate to separate from the mortar), in even layers of 15 cm. (6 in.) thickness, and rammed hard for three days with heavy rammers (see Figs. 52 and 53). The surface should be well watered. As a result of the ramming, cream of lime must rise to the surface. In no event should screeding mortar on the top be allowed to cover loose pieces of stone.

Figs. 52 to 60 show the excavator's and concretor's tools.



Figs. 52-60 :
Excavator's tools.
[See description on opposite page.]

Out of these, the sledge hammer and wedge are required for excavating soft rock or boulders. The chisel-edged end of the pick-axe is used for excavating soft earth and the tapered end for harder stuff. The smaller pick-axe is useful in narrow trenches. The square rammer is useful for consolidating concrete round corners and edges where the round rammer cannot easily reach. The boning rod is a T-shaped wooden instrument similar to a draftsman's T-square. Its use is illustrated in Fig. 60. Three such rods are required. When a long trench is to be excavated, for, say, laying a drain pipe either level or to a grade, the first and the third boning rods are held vertically on tops of pegs driven to the pre-determined levels. The excavation between them is made to such depths that the middle boning rod held vertically anywhere in the bottom, has its top just touching the line of sight of the other two.

Questions for Revision

(1) What is the purpose of foundations and what are the fundamental principles to ensure strength and stability of structures against uneven settlement?

(2) How can the bearing power of soils be improved?

(3) What are balanced foundations? Show by means of a sketch.

(4) How do piles support load? Under what circumstances are pile foundations most useful? How are piles driven?

(5) What is the difference between Simplex and Vibro piles?

(6) Describe the principles of grillage and raft foundation.

(7) Describe in detail supported by a foundation plan drawn to 1/100 scale the setting out of the foundations of a building 12 m. x 11 m. with outer and a middle longitudinal wall 1½ brick wide and two 20 cm. partitions at 3·5, 7 and 10 m. from the left hand side. Give dimensions on plan. Assume suitable width of footing.

(8) Sketch and name the different parts of timbers used in shoring foundation trenches 3 m. deep in dry soil.

(9) Calculate the maximum pressure on the base of the foundation of an independent column 2 m. x 2 m., if the vertical axis of the total 80 tonnes load passes through a point 35 cm. away from the centre of the concrete block one m. thick. *Ans:* 1·84 tonnes/m.^{2}

(10) The base of a 12 m. wall is 120 cm. wide and carries from the left hand end: 30 tonnes at 3 m., 50 tonnes at 7 m., 40 tonnes at 8 m. and 20 tonnes at 11 m. Calculate the maximum and minimum pressures. *Ans:* 1·48 and 0·58 tonnes/m.^{2}

FRAMED STRUCTURE AND BEARING WALLS : 2

THERE are primarily three systems of building a structure: (1) Framed Structure, and Filler or Panel Walls, (2) Load-bearing Walls and (3) A combination of these two.

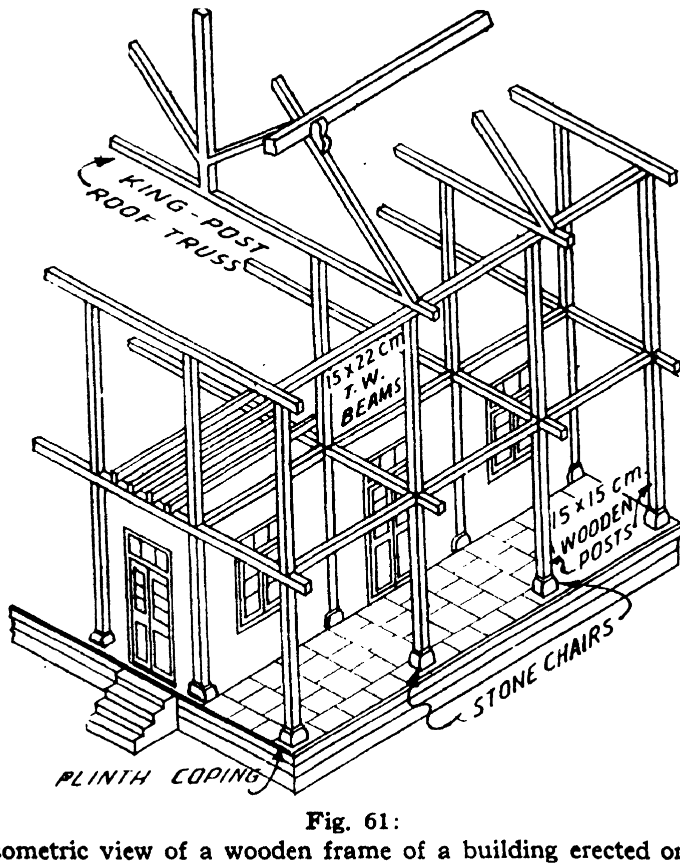


Fig. 61:
An isometric view of a wooden frame of a building erected on top of plinth.

In a framed structure, a system of columns or piers is erected on its own independent foundation and is braced together by

beams and floors. In this way the entire structure is erected, including the roof, and the gaps between the columns or piers are subsequently filled with walls which are called *panel, curtain,* or *filler* walls. The function of the panel walls is simply to serve as a screen for privacy and afford protection from the elements. They support their own weight only, the entire load on the structure—both live and dead—is carried by the frame.

The bearing walls are built on a continuous foundation and support the entire load, including their own.

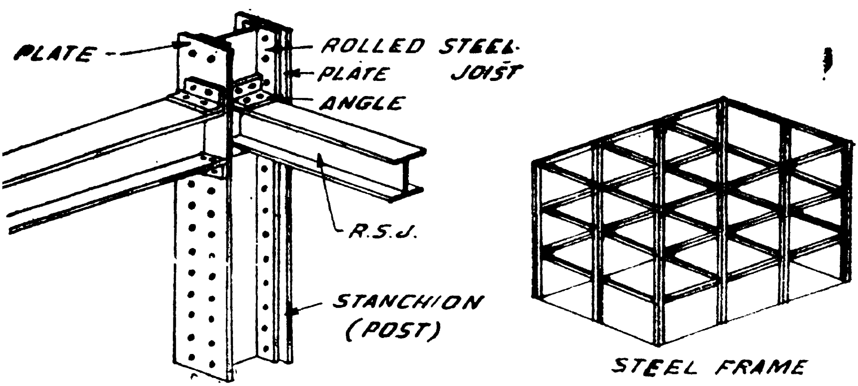
The third system, which is a combination of the two, is mostly adopted for buildings of residential type and consists of bearing walls on the outside and a frame of columns and beams with one end resting on the bearing walls, and the other on inner columns with thin partitions between the latter.

The advantages of the framed structure are:

(1) Increased floor space.

(2) Rapidity of erection.

(3) Ease of making subsequent additions and alterations to the structure.



Figs. 62, 63:
A simple steel frame and enlarged details of a steel stanchion and beams and their connections.

(4) Suitability to resist vibrations of machines such as in factories, earthquakes, or air-raids.

(5) Feasibility of larger rooms required for factories, etc.

For very light buildings of the cottage type, the frame may consist of wooden posts or beams (postplates or wallplates).

Some of them may be either partially or wholly embedded into the wall. In such cases, the wooden frame rests on walls which are built from the foundation to the plinth level. However, in course of time, the wood (particularly of the posts at their foot) rots, and ultimately the whole load falls on the filler walls, which are usually sufficiently thick, in the case of domestic buildings, as they are built for protection from the elements and thieves. Still, the life of such structures is shortened. Fig. 61 shows an isometric view of a typical wooden frame structure of a domestic building.

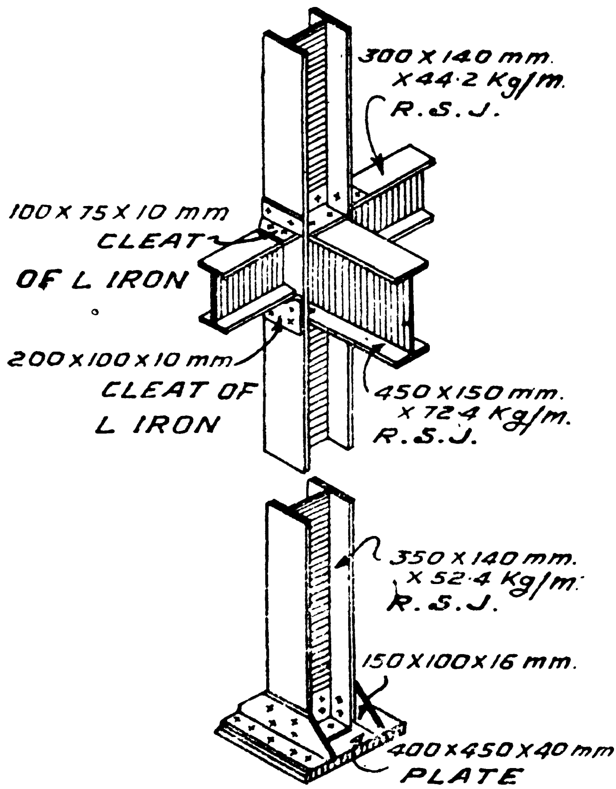


Fig. 64:
An isometric view of a steel stanchion with its base and beam connections.

In large buildings the frame may consist of mild steel or reinforced concrete. If of mild steel, the following practical points may be remembered.

(A) As far as possible curved or circular work should be avoided.

(B) Columns or stanchions supporting upper floors loads and roof should, wherever possible, be continuous from the basement and spliced when nesessary at about 50 cm. (1′ 6″) above the floor level. Where practicable, they should be so placed as to support directly the girders carrying heavy walls.

(C) Skew framing and eccentric loading should be avoided and the girders should be connected directly into the columns.

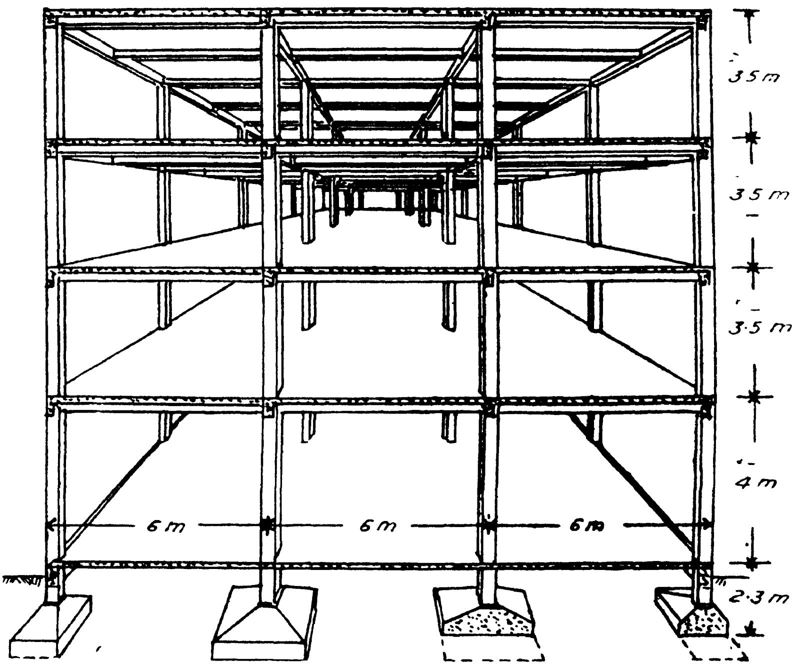


Fig. 65:
A framed structure of R. C. C. columns and beams.

(D) More stress should be laid on economy, ease of construction, erection, and subsequent upkeep (painting etc.,) than on mathematical accuracy in calculations. Cost of skilled labour is very often greater than the saving in weight.

(E) The basic principle of economic design, apart from the simple general lay-out, should be that each member subject to bending should be as deep as possible in the direction of maximum bending moment.

(F) The cleats may be so arranged that they may be riveted up mostly at the workshop, leaving as few bolts and rivets to be fixed at the site as possible, and the members should be self-supporting without the use of lifting tackle at the time of erection on site.

Some of the important joints of a steel frame are shown

elsewhere in the chapter on Structural Steel. A typical frame and a few connections are shown in Figs. 62 to 64.

A frame of R. C. C. has some advantages over a steel frame, viz.,

(1) Even the panel walls can be interconnected with the columns and beams, and thus the entire structure becomes monolithic.

(2) The construction is easy, as there are no joints to be riveted, welded or bolted.

(3) Steel is embedded into concrete and is thus better protected. A steel frame, on the other hand, requires, to be occasionally painted at considerable recurring expense.

(4) An R. C. C. frame is cheaper than a steel frame.

R. C. C. construction is discussed in a separate chapter.

A section of a 4-storeyed R. C. C. framed building is shown in perspective in Fig. 65.

Questions for Revision

(1) What are the advantages of a framed structure over load-bearing walls?
(2) What is the disability of a wooden frame?
(3) Why are R. C. C. frames fast superseding those of mild steel?

DAMP AND ITS PREVENTION : 3

DAMP is very bad from every point of view. Apart from the annoyance it causes by unpleasant smell, foul air, and mildew, which makes it impossible to store supplies of household goods, it is positively dangerous to health and also to the building structure. Damp, in the presence of warmth and darkness, breeds germs of tuberculosis, malaria, neuralgia and acute and chronic rheumatism can be directly traced to it.

It is no less dangerous to the building structure. When it rises into brickwork, certain salts, dissolved in it, also rise with it, and appear in the form of white deposits on the wall surface. These salts cause the exposed surface of brickwork to disintegrate and fall to powder. The action of damp on timber is no less destructive. The very common form of decay in timber known as *dry rot* is due to damp. The infection may take place at any stage in the life of timber and spread with amazing rapidity. It is caused by the growth of a certain fungus, and is carried from one place to another by spores. It is encouraged by dampness, warmth, and lack of ventilation.

The main sources of damp are:

(A) Damp rising from the soil either through the bottom or through the ground surface adjacent to the walls.

(B) Damp descending into the walls from a leaking roof whether sloping or terraced.

(C) Moisture penetrating the walls as a result of rain beating on them during continued wet weather, especially when the building occupies an exposed situation.

The insertion of a damp-proof course is obligatory under building byelaws in Western countries. In the tropics it is required only under special circumstances.

The damp-proof course consists of a layer of impervious material placed between the ground level and the plinth level.

The following precautions are suggested for the prevention of damp, before applying one of the remedies described later.

(1) In the first place, select a site to make sure that the first point at which water is struck in a pit is at least 10′ below the surface of ground even in the wet season.

(2) Make the ground surface surrounding the building, slope away from the house, so that rain-water drains away before it has time to collect.

(3) If the building is on a hill side, make sure that the land above the house is adequately drained *around* the building, and not *through* it.

The materials employed for water-proofing are either pore-filling, chemically or mechanically, or water-repellent. The water-repellent materials can be further sub-divided into bituminous or non-bituminous.

Four methods of damp-proofing are in general use:

(1) *Surface Treatment.*

(2) *Integral Water-proofing.*

(3) *Interposing a membrane* between the source of moisture and the part of the building adjacent to it.

(4) *Building hollow walls* with vertical cavities between the skins.

(1) **The surface treatment** consists in filling or blinding the pores of the material exposed to moisture, by providing a thin film of water-repellent material over the surface.

Some of the materials employed are: sodium or potassium silicates, aluminium or zinc sulphates, barium hydroxide and magnesium sulphate in alternate applications, soft soap and alum also in alternate applications, lime and linseed oil, coal-tar, bitumen, waxes and fats, shellacs, resins and gums, etc.

Out of these, some materials, like the waxes and fats are unsuitable in the tropics as they melt with a rise in temperature; resins and gums also are not lasting materials, and coal-tar and bitumen disfigure the original surface.

In any case, the surface treatment is useful only when the moisture is superficial, i.e., is not under much pressure, as in basements.

(2) **The integral treatment** consists in adding certain compounds to the concrete or mortar during the process of mixing. These vary from substances, like chalk, talc, fuller's earth, etc. which have simply a mechanical action of pore-filling and making the concrete or mortar denser, to alkaline silicates, aluminium or zinc sulphates, calcium, aluminium or ammonium chlorides, iron filings, etc. These react, chemically, and fill the pores. For instance, iron filings oxidise or rust and, in the process, increase in bulk. Most of the proprietary preparations like "Pudlo," "Sika," "Novoid," "Colemanoid," "Ironite," "Cementone," "Dampro," "Permo," "Rainex," etc., are based on this principle.

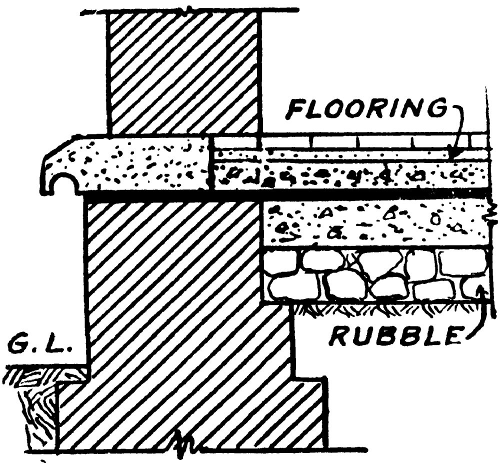


Fig. 66:
Damp-proof course on concrete just below plinth level.

(3) **Interposing a Membrane:** The third method consists in the incorporation of a membrane or a layer of a water-repellent material in the walls or floors. The materials employed are lead, either in plain sheets or bitumenised, terra cotta, and other hollow tiles, bitumastic felts, etc. Lead is very costly. Mastic asphalt in one or two layers is generally considered the best method where the hydraulic pressure is considerable. To be effective, the damp-proof course must extend unbroken through the entire length and thickness of the wall, irrespective of the changes in the level caused by the surrounding sloping ground.

In the case of ground floors, the best position for the D. P. C. is just below the plinth level.

If the sub-soil water table is high, and moisture is likely to rise also in the floor by seepage, aided by capillary action of the soil, a plain concrete floor, about 10 cm. (4″) thick, may be

constructed, upon it, an asphalt layer spread, and on the top of this, either another layer of concrete tiles or flagstones about 5 cm. (2 in.) thick, including the mortar bedding, may b e made as shown in Fig. 66.

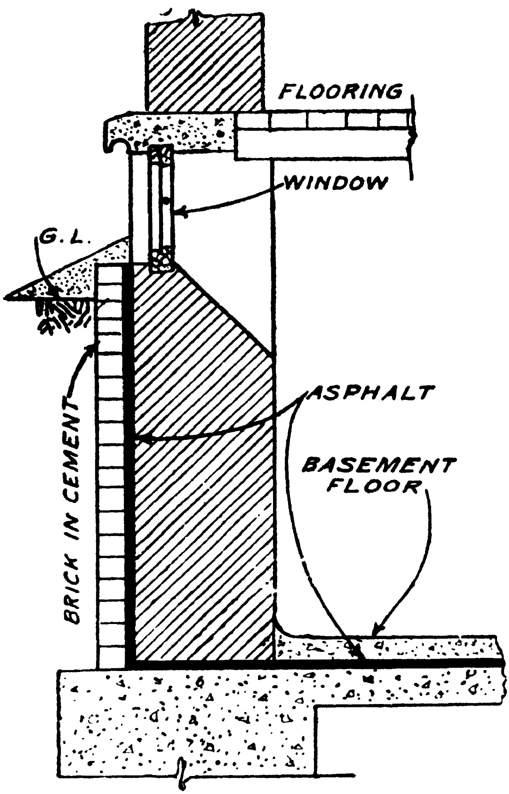


Fig. 67:
Treatment for water-proofing basement floor.

When the ground is sloping and the floor of the building is situated below it in certain parts, or if a basement floor is to be constructed, the damp-proof course should be laid 5 cm. (2 in.) below the top of the paving, as mentioned above, but continued through the thickness of the walls and up the vertical external faces of the walls, and terminated at, or better still 15 cm. (6 in.) above ground level on the outside. If there is a head of water, this should further be covered by 10 cm. (4 inches) of cement concrete, or of brick masonry in cement mortar on the outside as shown in Fig. 67.

If the head of water below the level of the floor is considerable, a horizontal and vertical damp-proof membrane should be interposed, as shown in Fig. 68, in which, below the level of concrete at the bottom of the asphalt membrane, a 10 cm. (4½″) layer of gravel is spread which will collect the seepage water below the floors. This water is drained to the outside of the external wall through communicating pipes buried horizontally through the concrete foundation walls. On the outside,

gravel is filled between the adjacent soil and asphalt membrane and 100 mm. (4″) drain pipes are laid around the footing, leading them finally with a suitable fall to a *nalla,* if nearby, or to a cess pit from which the water can be pumped out by means of a hand pump.

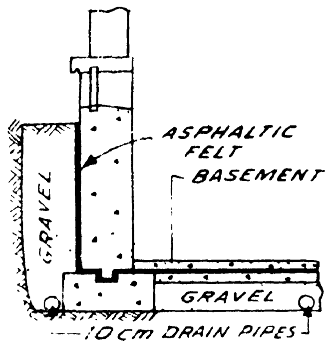


Fig. 68: Constructing a water-tight basement by providing a water-proof layer at bottom and sides and a drain pipe all round and below the cellar in gravel.

If the site of the building is swampy, or near the banks of a river subject to high floods, causing the sub-soil water level to rise high, the basements should be made water-proof by first forming a layer of mass concrete, about 15 cm. (6″) thick, over the entire area of the basement with one of the water-proofing compounds added in the concrete during the process of mixing, and on top of this, one or two asphalt membrane layers should be laid which should be continued vertically against the inner face of the basement walls to a height at least 15 cm. (6″) above the highest water mark. Then an R. C. C. slab designed to withstand the water pressure should be constructed. The reinforcement should be carried up the walls on the inner face to 15 cm. (6″) above the highest water mark, and covered under either 10 cm. (4¼″) brickwork in cement mortar, or 8 cm. (3″) of cement concrete, as shown in Fig. 69.

(4) **Building Hollow Walls:** Hollow brick walls are another preventive measure against damp. The walls are built usually with the *thick skin* of 22 cm. (9 in.) inside, as the air space of about 5 cm. (2 in.) between it and the outer skin of 10 cm. (4½ in.) brick wall is regarded as sufficient protection against damp. The two skins are bonded together by means of either galvanised iron wall ties or special patent vitrified bond bricks. The latter are not available in this country as hollow wall construction is also rarely practised here.

Figs. 70 and 71 show an isometric section and a plain vertical section respectively of hollow walls. In the former figure 10 cm. (4½″) skin is on the outside, and in the latter both are of 10 cm. (4½″) thickness. In Fig. 70 the cavity is ventilated by means of

special air-bricks. The damp-proof course is laid on the top of the second course of the cavity from the bottom. A G. I. wall tie is shown on the top of the wall. The cavity at the sill and head of the window is closed by means of a special steel cavity frame for the window.

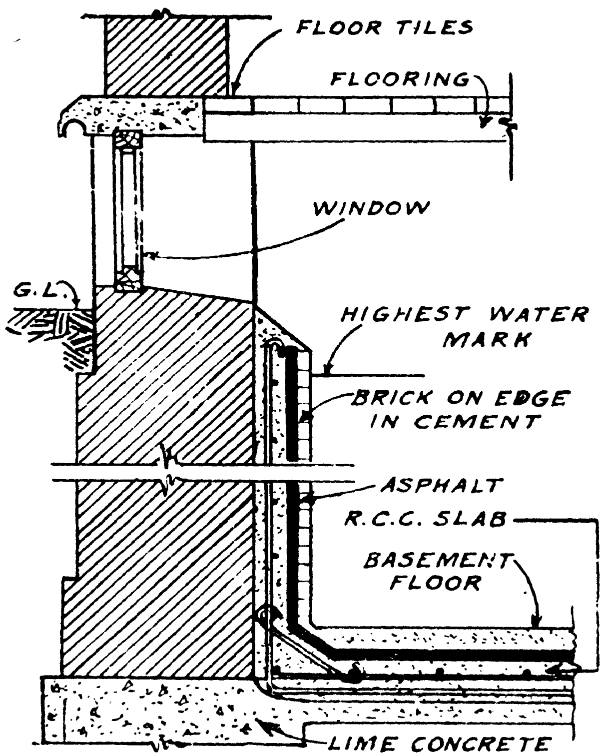


Fig. 69:
Treatment for water-proofing basement by R. C. C. floor and asphalt on a swampy site.

(B) **Damp descending from Leaky Roof:** Damp descending from a leaky roof is comparatively easy to remedy. Valley gutters are one of the fruitful sources of moisture descending into the walls below. The gutters themselves may be quite leak-proof. But while laying tiles, artisans carelessly cut the tiles a little too short, so that their ends, instead of overlapping and

projecting beyond the edge of the gutter, rest on the mortar joint on the sides of the gutter. Due to expansion and con-

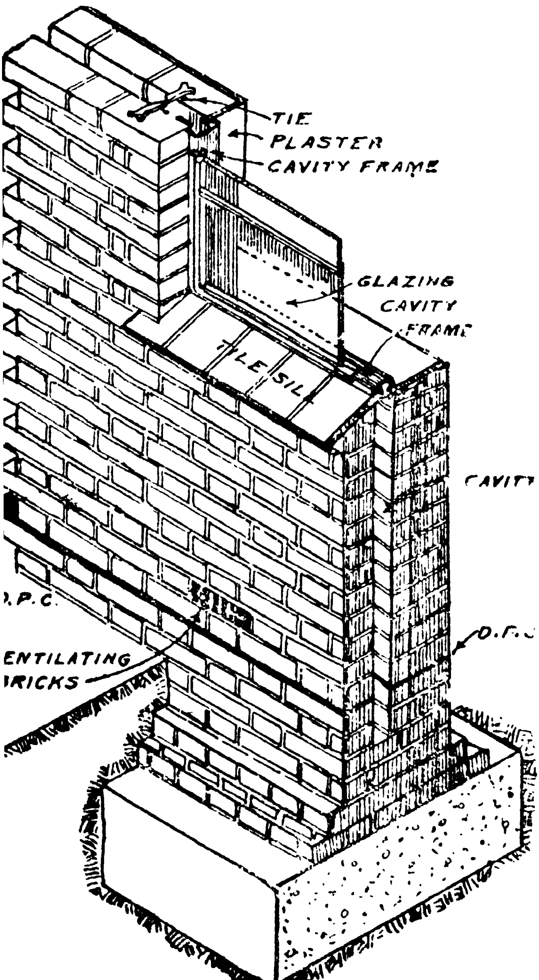


Fig. 70:
Hollow wall with thin skin on the outside. The
).P.C. is laid a few courses above the bottom of
ıvity. Note the ventilating bricks, cavity steel frame
f window and wall ties.

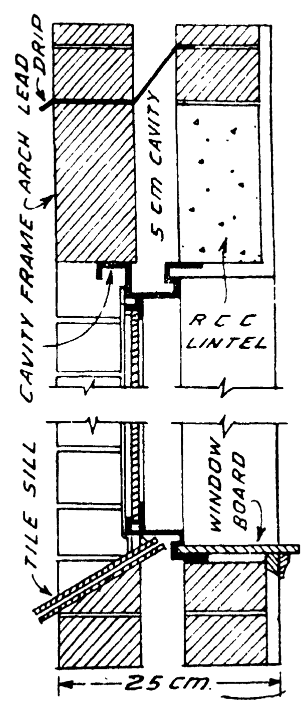


Fig. 71:
A vertical wall section of hollow wall with both skins of the same thickness.

traction caused by the difference in temperature in the exposed position, the mortar develops fine cracks through which rain-

water, in its passage from the tiles to the gutter leaks and ultimately flows down to the top of the wall, causing damp. The remedy is to cut the tiles in such lengths as to cause them to rest on the edge of the valley gutter and project at least 6 mm. (¼″) beyond.

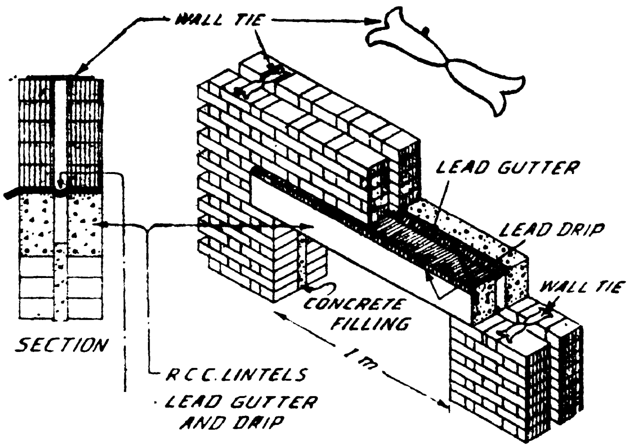


Fig. 72:
Vertical section of a hollow wall, showing lead gutter on the top of lintels.
Fig. 73:
Isometric section.
Fig. 74:
Enlarged view of a metal wall tie.

Another remedy is to lay strips of bitumastic felt sheets or dungry cloth soaked in bitumen on sides and tops of valley gutters so as to lie at least 5 cm. (2 in.) below the edges of tiles.

In the case of flat roofs, and also in the case of a sloping roof with a parapet wall at the end of the slope, the gutter behind the parapet wall lies exactly over the top of the wall below, since the parapet wall is thinner than the lower wall. In such cases, if the gutter is plastered with mortar,—either of cement or lime—as is usually the case, fine cracks are formed on its surface, and through these, water leaks on the top of the wall below. The remedy is either to construct the gutter of half-round stoneware or asbestos cement pipes, or, better still, line it with sheet lead, or if of concrete or brick-work, to line it with

some water-repellent elastic material, such as asphalt or bitumen and to provide lead drip as shown in Fig. 75.

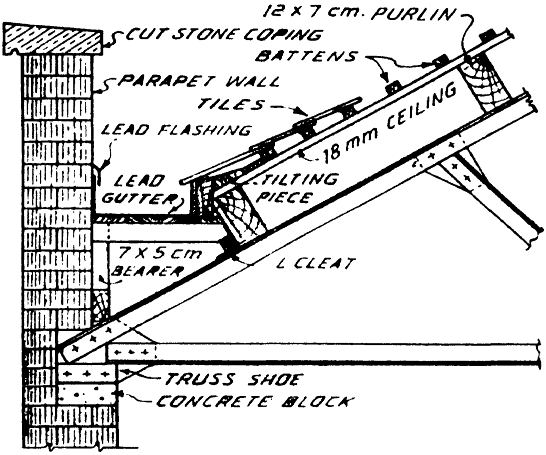


Fig. 75:
Parapet wall at the end of a sloping roof. The gutter behind it is lined with lead.

If the flat roof is used as a terrace, and, in consequence, there is no gutter built behind the parapet wall, the following precautions may be taken:

(a) There should be a good and even slope given to the terraced surface—1 in 36 is the minimum slope required.

(b) Rain-water spouts or down-take pipes of sufficient capacity and at proper intervals may be provided.

(c) The surfacing of the terraced roof should be either of some water-repellent, resilient material, or tiles laid on asphaltic felt, or of broken china or similar material in which the effects of expansion and contraction are minimised on account of innumerable joints in the surface.

(d) All the corners and edges should be rounded, and whatever surface treatment for water-proofing is adopted, it should be carried 10 to 15 cm. (a few inches) vertically against the wall, flush with plaster as shown in Fig. 76.

(C) **Moisture Penetrating the Surface of Walls:** The preventive measures are:

(a) The exterior wall should be of sufficient thickness. If of brick, it should be of a minimum thickness of 1½ bricks.

(b) The face bricks should be of good quality and of low absorption coefficient. If the wall is of stone, there should be no hollows left inside, and the joints on the exposed face should be pointed with cement.

(c) Covering the exposed surface with cement plaster in which some water-proofing compound may be mixed.

(d) *Chajjas,* string courses, and cornices should be provided. Window sills and coping of plinth and string courses should be sloped on top and throated on the underside to throw the rain-water off the face of walls.

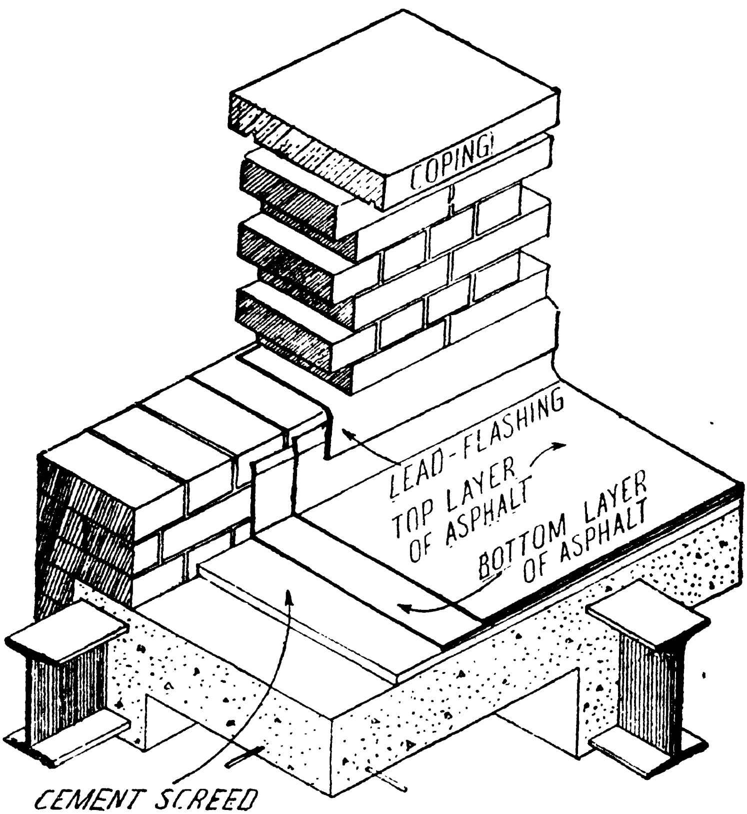


Fig. 76:
Isometric section of part of terraced roof, showing lead flashing and two layers of asphalt which are carried below the flashing.

If there is incessant rain, accompanied by high wind, such as near the sea-coast or at hill-stations, the following additional precautions may be required.

(e) Building a 9 cm. (4½″) brick wall on the outer side of the walls exposed to heavy, piercing rain, leaving a cavity of

20 mm. (¾″) to 25 mm. (1″) between, in which hot asphalt may be filled gradually as the work progresses.

(f) Protecting the exposed face by erecting *tatties* of hay or bamboo matting, temporarily, during the wet season. The bamboo matting needs to be painted with coal-tar on the outside, which makes it repel water, and also prolongs its life.

Plinth: Plinth masonry, on account of its thicker section, adds to the stability of the walls. It helps protect the house from damp and enhances the architectural appearance. Usually, a coping either of finely dressed stone, or concrete, is provided at the top, which projects a little on the outside with a drip moulding on the underside in the projecting part and a slope on the top. The minimum height of the plinth should be 45 cm. (18″).

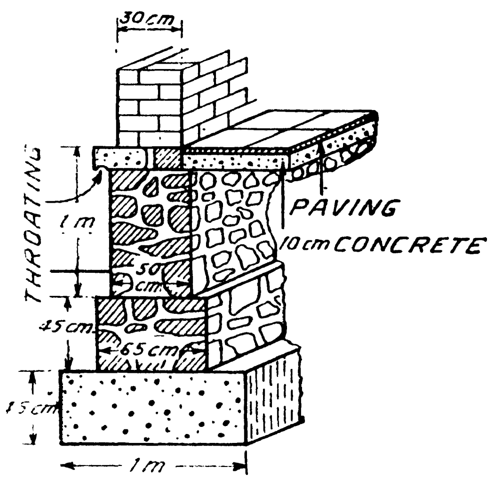


Fig. 77:
Section of a wall, showing the foundation, and coping at plinth, with throating.

Plinth masonry, being near the ground level, is subjected to greater wear and tear, such as erosion by flow of rain-water, action of salts in the soil, splashing rain-water, damage by abrasion, etc. Hence, as far as possible, if stone is used for the foundation, it should be continued up to the top of the plinth; or, if stone is scarce, well burnt bricks should be selected for the facing.

Questions for Revision

(1) What are the evil effects of damp on human health and building structure?
(2) Mention the main sources of damp affecting a building.
(3) How can damp be prevented?

(4) Classify the different methods of damp-proofing.
(5) How can a basement floor be made damp-proof (i) under ordinary circumstances, and (ii) when the sub-soil water is under pressure? Illustrate with sketches.
(6) How can the damp descending from leaky valley gutters or gutters behind parapet walls of terraced roofs be prevented?
(7) What purposes are served by the plinth course and what are its requirements?

MASONRY : 4

BROADLY speaking, there are two classes of masonry, viz., (1) Stone masonry, and (2) Brick masonry. These two main types of masonry can be further sub-divided according to the workmanship and the type of materials used. Before entering into the various sub-divisions of masonry, it is proposed to give here the comparative merits and demerits of the two main types.

Stone Masonry *Versus* **Brick Masonry:** Obviously stone is stronger and more durable than brick, and for public buildings of a monumental nature, it is decidedly more suitable than brick.

A stone building reflects strength in every inch of it, it is in tune with nature, its colour improves and looks more serene with age.

While stone is a natural building material, brick is artificial, a product manufactured in imitation of stone; the latter is a comparatively flimsy material, and plastering is only a camouflage to conceal defects.

Brick absorbs moisture and is liable to make the building damp. With damp, certain salts also rise in the walls from the ground and cause disintegration of the bricks.

Brick cannot be allowed to come in contact with urine or sewage, and therefore, in such places it must always be covered with cement plaster.

Although stone is stronger than brick, the latter, if of good quality, is sufficiently strong for ordinary purposes and more convenient when protected by cement plaster on the exposed surfaces. It also possesses certain other advantages over stone.

Brick offers greater facility for ornamental work in plaster, as a rough shape can first be given to it by means of an axe. This is not so with stone. It must be finely dressed for ornamental effect at great cost. Plaster does not stick so well to stone as it does to brick.

On account of the regular shape and uniform size of brick, a proper bond can be obtained with comparative ease. For the same reason, and also because of the handy size of brick, brick masonry can be more speedily constructed than stone masonry, as stones do require some dressing, even for the most inferior type of work, in order to make them fit into the work. For jambs of doors and windows, and for walls meeting at obtuse and acute angles, brick offers far greater ease and convenience than stone.

Brick wall requires a fixed quantity of mortar, and even with careless masons the regular shape of the brick considerably reduces the possibility of hollows being left in the body of a wall. This is not so with stone wall.

It is possible to build brick walls of any thickness, viz., 8, 10, 20, 30 cm. (3″, 4½″, 9″, 14″) and above, whereas the minimum thickness of ordinary stone wall is 38 cm. (15″). This is on account of the large size and irregular shape of the stone; stone walls of a smaller thickness than 38 cm. (15″) have to be constructed with properly dressed stones which involve a comparatively high cost.

Brick does not absorb as much heat as stone does—a matter of considerable importance in the tropics where the problem of mitigating the heat inside rooms for comfort, has to be faced. Brick is also more fire-resisting than stone.

Definitions of Terms Used in Masonry: (1) *Face and Facing:* The exposed surface of a wall or a structure is called the Face, and the material which forms the face is called the Facing.

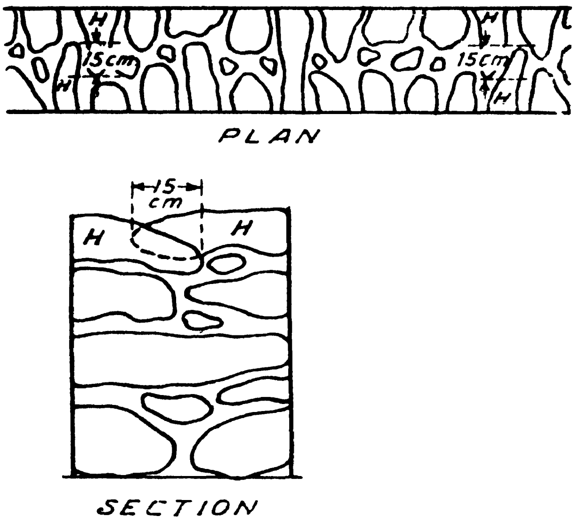
(2) *Back and Backing:* The inner surface of a wall which is not exposed is called the Back, and the material forming the back is called the Backing.

(3) *Filling or Hearting* is the interior portion of a wall between the Facing and Backing.

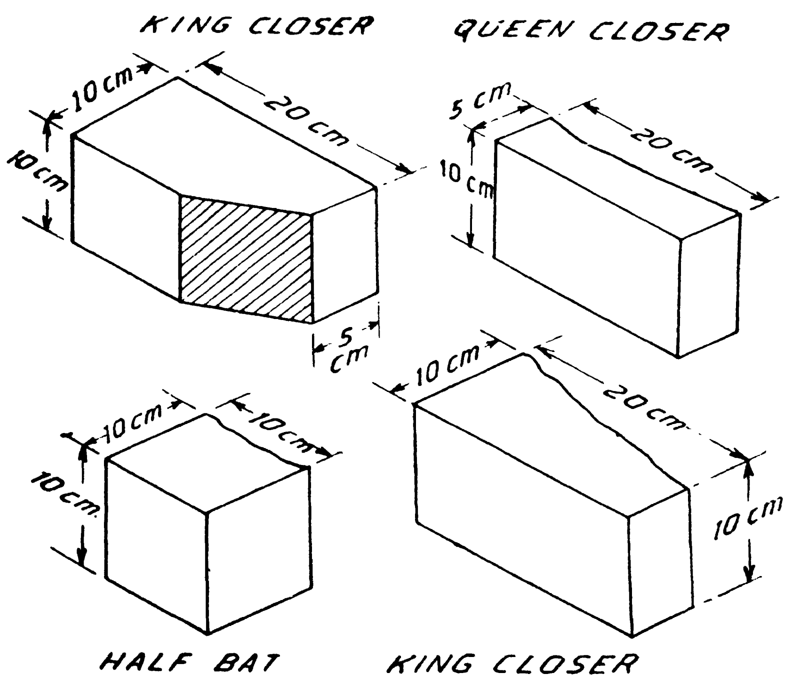
(4) *Bed:* The lower surface of stones or bricks of each course is called the Bed.

(5) *Sides* are the surfaces forming the boundaries of bricks or stones in a direction transverse to the faces and beds.

(6) *Joints:* The mortar joints between the courses normal to the principal pressure are called the *Bed Joints;* the joints transverse to the beds and faces are termed the "Side Joints" or simply "Joints."

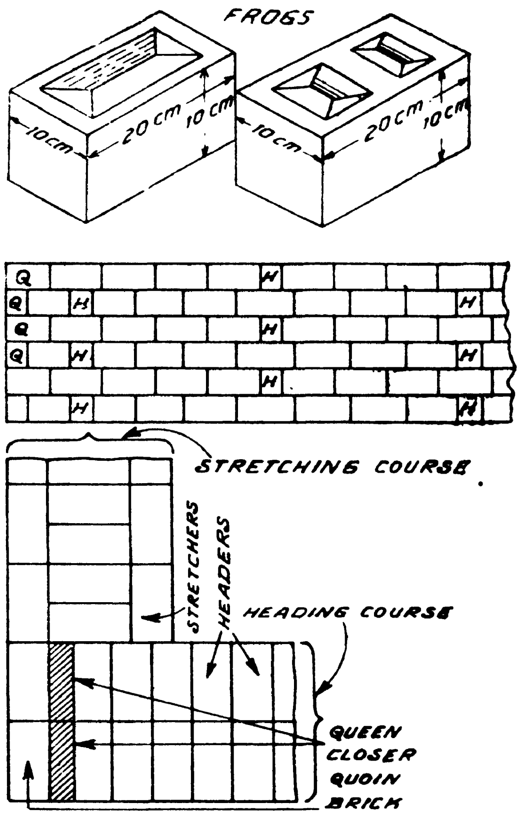


Figs. 78, 79: Plan and cross section of a coursed rubble wall, showing through stones and bond stones or headers (HH) whose tails overlap each other by 15 cm. (6″) or more.



Figs. 80-83.

(7) *Courses:* Each horizontal layer or slice of masonry between successive bed stones is called a course.



Figs. 85-88: The letters "Q" in Fig. 87 indicate quoins or corner stones or bricks. "H" "H" are headers or bond stones, laid at five feet intervals. The headers in successive courses are staggered.

(8) *Header* is a brick or stone which lies with its greatest length perpendicular to the face of the work. (Figs. 78, 79).

(9) *Stretcher* is a brick or stone which lies with its longest side parallel to the face of the work (Fig. 88)

(10) *Bond* is the arrangement of bricks or stones in each course so as to ensure the greatest possible interlocking and to avoid continuous vertical joints in two successive courses both on the face and in the body of the wall.

(11) *Through Stones* are headers which extend from one face of a structure to the other so as to bind the two faces together.

(12) *Spalls* are chips of stones used for packing up and filling the interstices in stone masonry.

(13) *Quoins* are the stones used for the corners of walls of a structure. (Fig. 87).

(14) A *Quoin Brick:* A brick forming a corner in brickwork is known as a *Quoin Brick*. It has one end and one side exposed to view. (Fig. 88).

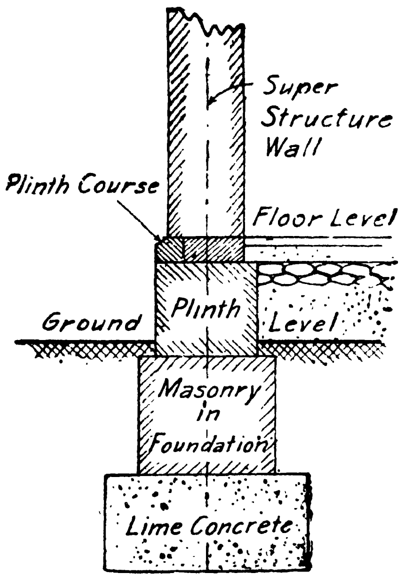


Fig. 89:
Vertical section of a wall, showing, parts from foundation to superstructure.

(15) *Queen Closers* are bricks half as wide as full bricks, and are made by cutting a whole brick lengthwise into two portions (Fig. 81). They are generally used next to the Queen Header for creating bond in brickwork.

(16) *King Closers* are bricks so cut that, one end is nearly half the width of a full brick (Figs 80 and 83). They are used in the construction of jambs.

(17) *Squint Bricks* are used for forming acute or obtuse corners in brick masonry. These are special forms of bricks.

(18) *Frog* is an indentation on the top surface of a brick, made with the object of forming a key (hold) for the mortar, and incidentally also for reducing the weight of the brick (Figs. 85 and 86).

(19) A *Stretching Course* is one in which all the bricks are laid as stretchers. This term is sometimes used for indicating a

course in which all the exposed bricks are laid as stretchers (Fig. 88).

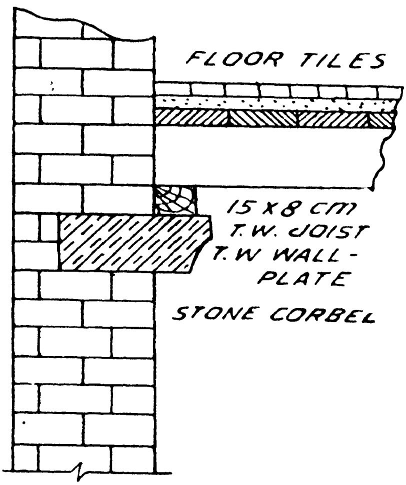


Fig. 90:

(20) A *Heading course* is one in which all the bricks are laid as headers (Fig. 88).

(21) *Footings* are the projecting courses which are built at the bottom of a wall with the object of distributing the pressure over a large area of the foundation. (Fig. 89).

(22) *Plinth* is the horizontal projecting course or courses with the top flush with the floor level, resting on masonry in foundation, and forming the base of the superstructure walls. This term is also used to indicate the height of the ground floor level above the ground.

(23) *Plinth Course* is the topmost course of the plinth masonry.

(24) *String Course* is a horizontal projecting course of masonry—usually ornamental—built in the face work for shedding rain-water off the face and incidentally imparting an architectural appearance to the structure (Fig. 91). String courses are usually introduced at every floor level.

(25) An *Eaves Course* is that course of masonry which is immediately below the eaves or the horizontal finish to the roof.

(26) A *Corbel Course* is one (or a series of courses) which projects (or project) to provide a ledge for structural purposes such as a support for wall plates, etc. (Fig. 90). In corbelling with brick-work, each course should be of headers not projecting more than one-fourth brick beyond the lower course. In stone masonry the stones forming the corbel course must be sufficiently embedded in and anchored into the body of the wall.

(27) A *Coping* is a course placed upon the exposed top of

a wall to prevent moisture from entering and soaking into the masonry (Figs. 92 to 96). It should, therefore, be of an impervious material containing as few joints as possible, and should be set in hydraulic lime mortar or cement.

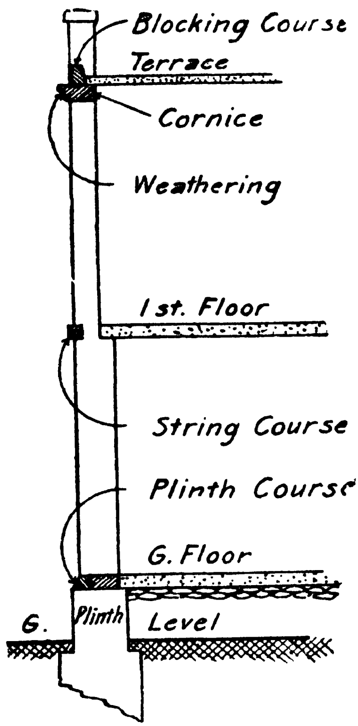


Fig. 91:
Section of a wall, showing different parts from ground level to top.

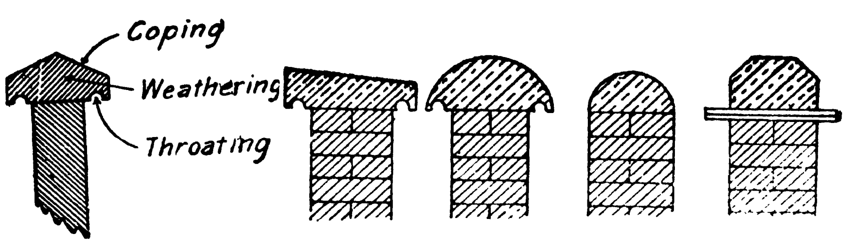
The upper surface of a coping should be "weathered" or sloped to throw off the rain-water. The coping should project a little beyond the faces of the wall and throated so that the water may fall clear of the surface of the wall below.

For different types of copings see Figs. 92 to 96.

(28) A *Cornice* is a projecting ornamental course or courses near the top of a wall (Fig. 91).

(29) A *Blocking Course* is the topmost course of stone surmounting a cornice. It adds to the appearance and, by its weight, prevents the tendency of the cornice to overturn (Figs. 91 and 133).

(30) *Jambs* are sides of the openings (Figs. 97 and 98).



Figs. 92-96:
Different forms of coping with weathering and throating.

They may either be square or splayed and may be provided with recesses to receive the frames of doors and windows. Openings

with splayed jambs weaken the wall more than when the jambs are square. Splayed jambs are, however, convenient, as they afford room for a shutter which otherwise would obstruct the passage.

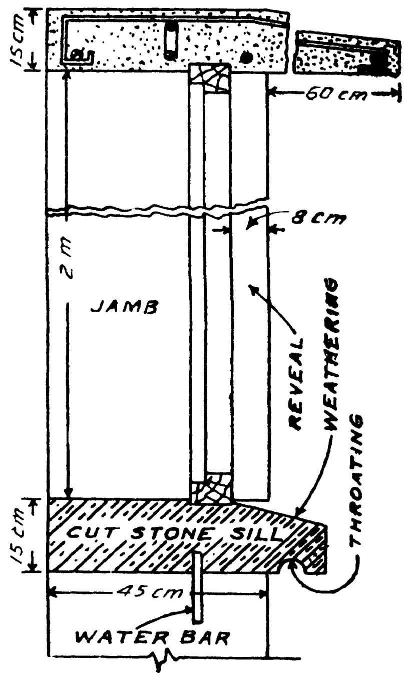


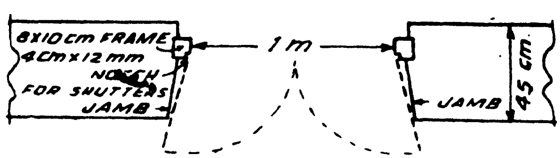
Fig. 97:
Vertical section of a window, showing various parts.

(31) *Reveals* are the portions of the sides of the opening left in front of the recess for the door or window frame (Fig. 97). They are probably so called because they are revealed or exposed to view, whereas the rest of the sides of the openings are hidden. The width of the reveal is generally 8 to 10 cm. (3″ to 4″).

(32) *Sill* originally meant the piece of timber at the bottom of a door or window supporting the vertical members of the frame, but now the term is applied to the horizontal part, either of timber, concrete or stone, forming the bottom of openings.

(33) *Pier* is an isolated mass of stone or brick masonry built to support beams, lintels, etc. It is also applied to the intermediate support of a series of arches.

Fig. 98:
Plan of a door showing reveal and splayed jambs.



(34) *Pilaster* is a flat column of masonry attached to a wall, and projecting a little beyond it, to support a concentrated load such as the end of a beam or truss of a roof.

(35) *Pillar* is a vertical isolated support of concrete or masonry of round or rectangular section supporting a load.

(36) *Buttress* is a sloping or stepped masonry projection from a tall wall, and intended to strengthen the same against the thrust of a roof or a vault.

(37) *Parapet* is the dwarf wall along the edge of a roof or round a terrace, etc., to prevent persons from falling (Figs. 91 and 75).

Stone Masonry

Dressing of Stone: Stone as removed from the quarry is very irregular and therefore unfit for being used in masonry before being subjected to some cutting and dressing. The amount and type of cutting and dressing depends on the kind of work for which the stone is required.

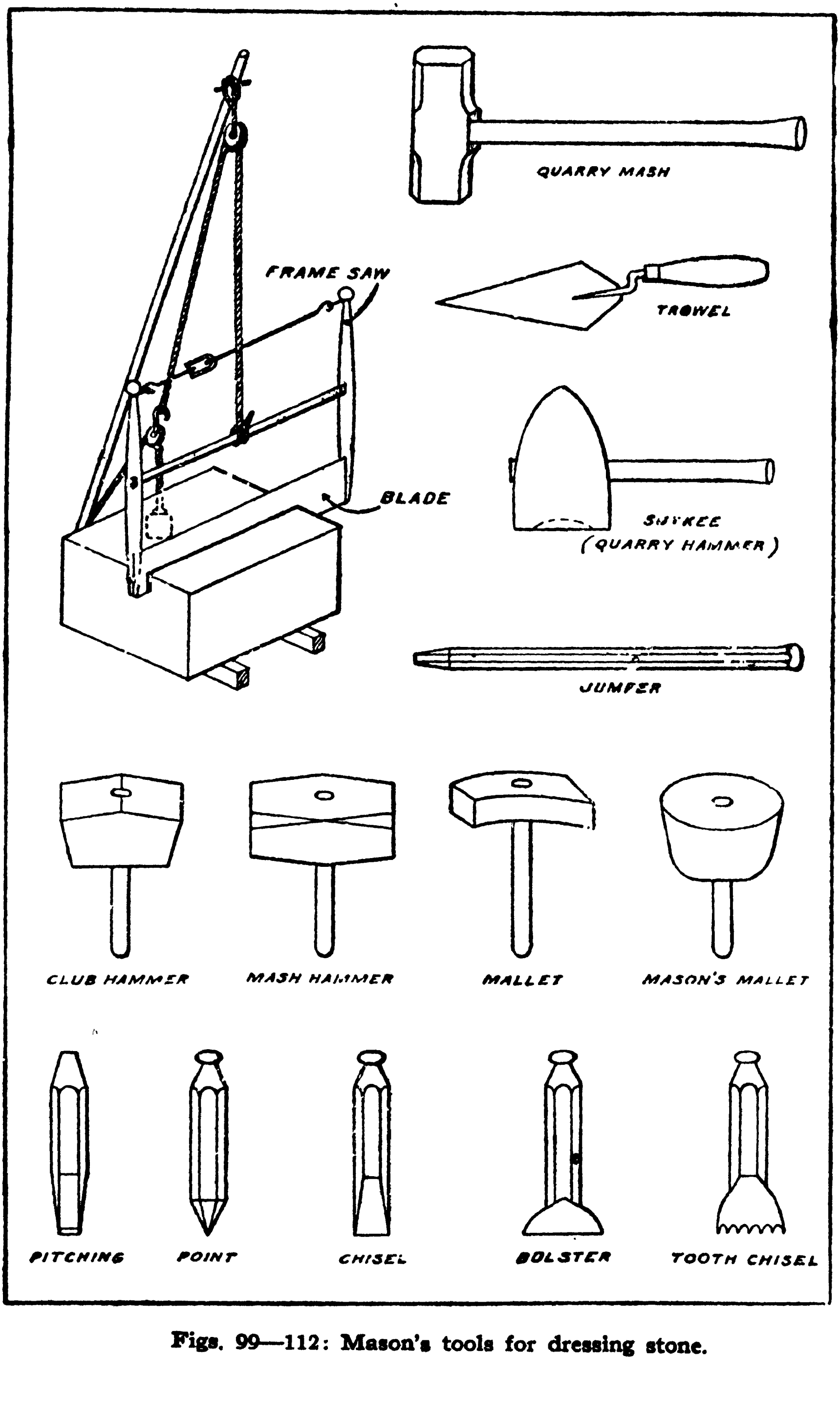
The implements and tools used for cutting and dressing are illustrated in Figs. 99 to 112 and their use is briefly explained below.

(a) The sledge hammer and (b) the bar jumper are used for punching holes for blasting purposes. (c) The quarry hammers (*sutkees*) of varying weights are used for breaking up larger blocks into pieces of suitable size. (d) The frame saw, which is slung from an overhead pulley and rocked to and fro, is used for sawing blocks of soft stone (e. g., Porbunder limestone.) The blade is of steel about 10 cm. (4″) deep without teeth and 1·25 m. to 4·5 m. (4 feet to 15 feet) long. It is fed with sand or shots of cast steel and water during the cutting process. The cross-cut saw and the hand-saw, similar to those used by carpenters, are also used. These are not illustrated.

The tools so far alluded to are used on the quarry for roughly shaping and dressing stones.

The tools used for finer dressing are illustrated in Figs. 104 to 112.

(a) The club hammer, 1 to 1·5 kg. (2 lbs. to 3 lbs.) in weight, and (b) the mash hammer, 1 to 2 kg. (2 lbs. to 4 lbs.) in weight, are used for driving narrow-headed steel chisels; and (c) the wooden mallet, 12 to 20 cm. (5″ to 8″) in diameter is used, with broad-headed chisels for dressing soft stone. Of the chisels in use, those given in Figs. 108 to 112 are the most common. (a) The pitching tool has a broad thick edge for reducing stone to the required size; (b) the point has a pointed edge;



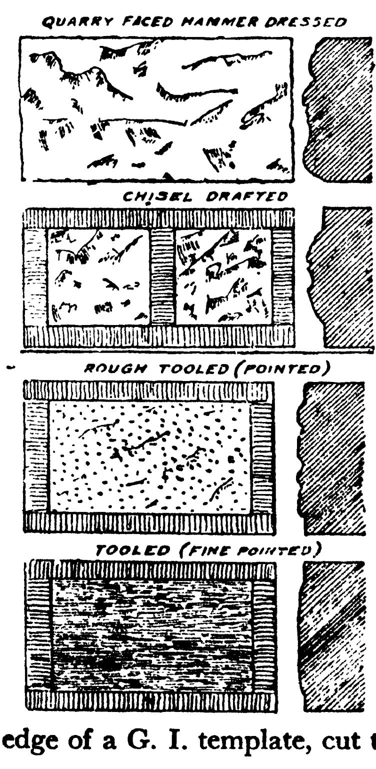
Figs. 99—112: Mason's tools for dressing stone.

(c) the inch tool has an edge 25 mm. (one inch) wide; (d) the bolster has an edge 5 cm. (two inches) wide; and (e) the broad tool has an edge over 5 cm. (two inches) in width.

Dressing of stone is done in two operations. As soon as a stone is removed from the quarry, it is broken up into suitable pieces by means of quarry hammers (*sutkees*), and stones suitable for *khandkis,* corner-stones, through-stones, headers, and cubical blocks, etc., are separated. These are then roughly dressed to shape and size by means of small quarry hammers.

Further dressing of stone is generally done at the site of the building as described below.

To reduce an irregular surface to a plane surface, a rebate about 2.5 cm. (an inch) in width is worked at two opposite edges of the surface; the parallelism of these rebates is ensured by testing it with winding strips and straight edges. A similar rebate is worked on the two remaining edges, connecting those first made. A continuous margin or rebate is thus formed about the four edges of the stone, every portion of which lies in one plane. If the stone be small, the irregular excrescence is then removed with a chisel to the level of the rebate. For large surfaces, subsidiary draughts are formed traversing the stone between the rebates.



Figs. 113, 114, 115, 116, 117, 118, 119, 120

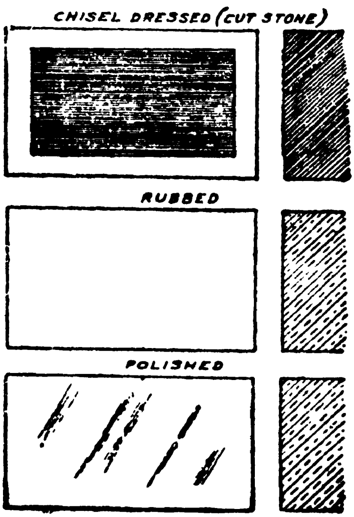
Mouldings are worked on stone in the following manner: The ends of the stone are first roughly planed and the profile of the moulding is marked on these by means of a pointed tool drawn round the edge of a G. I. template, cut to the shape of the required profile.

A draught is then sunk in the two ends to the required shape, the superfluous stuff is then cut away with a chisel, the surface between the two draughts being tested for accuracy by means of a straight edge.

Stone surfaces is general, and the exposed surface in particular can be finished in a number of different ways. The common varieties of surface finishes are illustrated in Figs. 113 to 126 and are briefly described below.

(i) *Self-faced, Quarry-faced or Rock-faced Surface:* This term is applied to the natural surface formed when a stone is detached from the mass in the quarry or to the surface of fracture formed when the stone is split into two. This also includes the roughest description of dressing with a small quarry hammer with which large projections are knocked off and the surface roughly planed.

In walls finished with rock-faced or hammer-dressed surfaces, *chisel-draughted margins* about 2 cm. (1 in.) in width are sunk about the four edges of the exposed surface to ensure accuracy of work. (See Figs. 115, 116).



Figs.
121
122
123
124
125
126

Figs. 113—126:
Different varieties of dressing stone shown in elevations and sections.

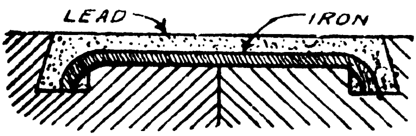
Rough Tooled Surface: The term is employed for the surface approximately dressed true by means of a pointed tool or punch. This type of work is often done on the side and bed joints, but occasionally it is also used to give a bold appearance to quoins and plinth stones. When so used, the surface is always surrounded by chisel-draughted margins. (Figs. 117, 118).

Tooled Surface: This term is used for the surface truly planed by means of a chisel, care being taken to keep the chisel

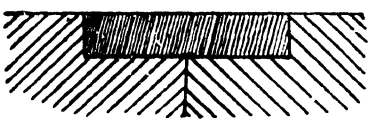
marks in continuous lines across the width of the stone. The object of this is to increase the effect of large plane surfaces by adding a number of shadows and highlights. (See Figs. 119, 120).

Fine Chisel-Dressed or Cut Stone Work: A surface dressed true and out of winding with a sharp chisel so as to give an appearance of hewn stone. In this type of work the chisel marks are practically imperceptible. (See Figs. 121, 122).

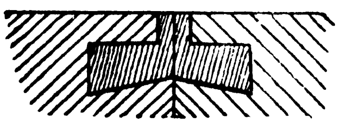
Figs.



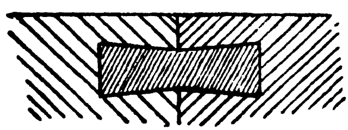
127 G. I. CRAMP



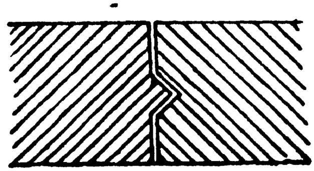
128 LEAD PLUG



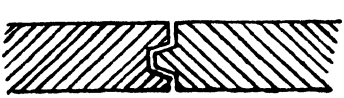
129 LEAD DOVETAIL



130 SLATE CRAMP



131 JOGGLE JOINT



132 JOGGLE JOINT

Rubbed Surface: If a smoother finish than that of fine chisel dressed work is required, previously planed surfaces may be rubbed until they are perfectly regular and smooth. This can be accomplished by manual labour by rubbing one piece of stone against another. During the first stages of the work, water and sand are added, the quantity of sand being gradually reduced up to the finish. (Figs. 123, 124).

Sometimes the stones are machine-rubbed by means of large, horizontal, revolving iron discs. The stones are placed on the disc and are prevented from revolving with the same by means of stationary timber pieces fixed across the table. No pressure is applied other than the weight

of the stone itself. Water and sand are added to accelerate the process.

Polished Surfaces: (Figs. 125, 126) Dense stones like marble granite, or basalt after being worked to a smooth surface, are often polished by means of rubbers and pads, sand and water, pumice stone, snake stone or putty powder. Polishing the stone by manual labour is a tedious operation, and to obtain the same result, the modern practice is to use revolving carborundum wheels and discs worked by machine power.

Joints and Connections Used for Securing Stone in Masonry Work: Since the advent of reinforced cement concrete, in which strong and monolithic mass construction is possible, the use of stones in places requiring special precautions for securing them, is now-a-days avoided. However, it will be interesting to study in brief the methods formerly adopted in such cases.

To prevent longitudinal movement in copings, blocking courses, etc., metal cramps of iron, copper or bronze, 22 cm. × 4 cm. × 12 mm. (9″×1½″×½″) (Fig. 127), or lead plugs (Figs. 128, 129) are used.

To prevent lateral movement along the bed joints, bed plugs of hard stone, slate, or metal (Fig. 130) are used.

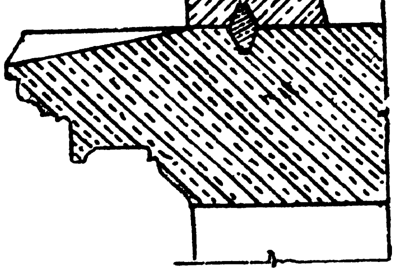


Fig. 133:
A vertical section of a stone cornice with blocking course above, showing that they are joined by a bed plug.

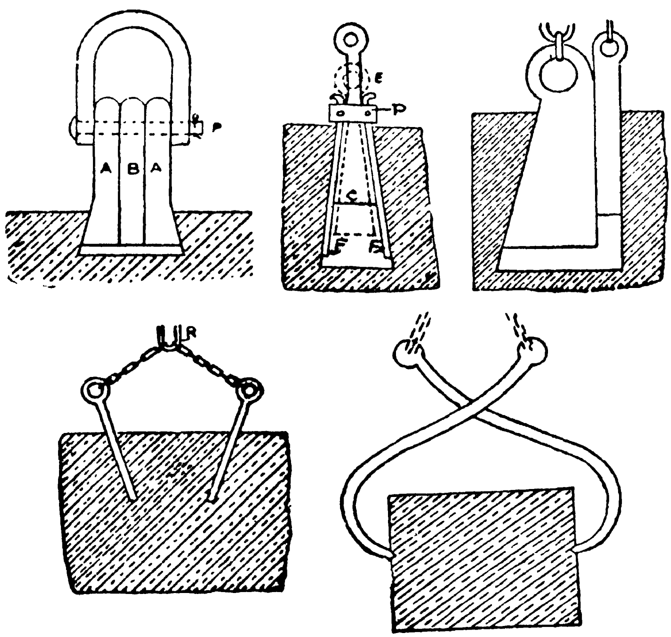
To prevent sliding along the side joints, slate dowels or joggles are used. These are illustrated in Figs. 121, 122.

Methods of Securing Stones to be Lifted: Stones which are rough or hard may be lifted by chains passed round them, but when finely dressed and soft stones are to be hoisted and placed accurately in their final position, a special tackle (such as a Lewis or a pair of Nippers) is required.

There are many kinds of Lewis as shown in Figs. 134 to 138.

Fig. 134 illustrates a Lewis in three pieces fixed in a corresponding tapering hole in the stone. The dovetail-shaped pieces A, A are first inserted and placed against the sides of the hole. The central piece B is next put in and the three pieces and the hoisting ring are secured together by means of a pin P. When the stone is being lifted, the Lewis, on account of its shape, becomes tightly jammed and the stone cannot slip down.

Fig. 135 illustrates a Lewis which is an improvement on the type previously described. The central wedge-shaped piece C, with an eye E for fixing the hook of the lifting chain freely slides between the two plates P. The pieces F are placed between the plates P and are hinged to them by means of two pins. When



Figs. 134—138:
The first four are different varieties of Lewis for lifting large stones, and the last is a pair of nippers used for the same purpose.

the Lewis is to be lifted, the central wedge-shaped piece C is slid down so that the lower ends of the two pieces F fall in, as shown by dotted lines in the figure. The Lewis is inserted in the hole, and the central piece C is lifted up so that the pieces F are pushed

apart and the Lewis tightly fits into the hole. When the stone is placed in its final position, the central piece E is hammered down and the Lewis withdrawn.

Fig. 136 illustrates a Lewis for lowering and setting stones under water.

Fig. 137 shows another very simple type of Lewis. It will be seen that due to the inclination of the holes in the stone, an upward pull applied to the ring R draws the heads of the two pins toward one another and makes it impossible for the pins to come out.

Fig. 138 illustrates a pair of Nippers, the action of which is very similar to that of a pair of tongs. For obvious reasons, the notches, in which the points of the Nippers fit, must be above the centre of gravity of the stone, but with a sufficient margin from the top.

General Principles to be Observed and Precautions to be Taken in Constructing Stone Masonry: (i) As a rule, every stone in ordinary walls and arches should be laid upon its "natural bed," that is to say, the bed upon which it rested when originally formed should be perpendicular to the direction of the principal pressure.

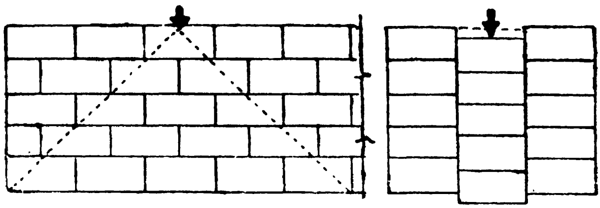
When a stratified stone in a wall is placed vertically so that the layers of which it is formed are parallel to its face, the layers are apt to be split off in succession by the action of the weather. Moreover, the stone in this position has not so much strength to resist crushing as it would have had, had it been placed on its "natural bed".

Stones projecting from the wall, such as corbels and cornices, are exceptions to this rule. These should be so placed that their natural bed is parallel to the joints. If the natural bed is horizontally placed, the layers in the overhanging portion are likely to drop off.

(ii) The masonry should be so constructed that a proper bond is maintained throughout the work. A good bond in walls breaks vertical joints both in the length and thickness of the wall, giving the stones a good lap over one another in both directions so as to afford as much hold as possible between the different parts of the wall.

A further effect of a bond is to distribute the load that comes on each stone on a number of stones below. (See Fig. 139).

It should, therefore, be observed that the vertical joints break upon every stone, and that through stones or overlapping headers are used at regular intervals. The overlapping headers, inserted from both faces, should extend inwards for a depth equal to about 2/3 the thickness of walls when this thickness does not exceed 1.25 m. (4 feet). For greater thickness of walls, a row of headers overlapping each other for a length of about a foot should be used.

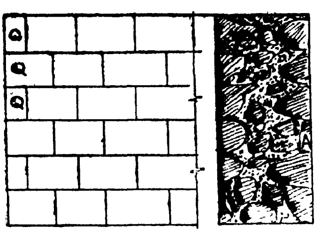


Figs. 139, 140:

The break of joints in the wall in the left-hand figure causes the load to be distributed over a large area between the dotted lines.

In the right-hand figure the continuous vertical joints, apart from concentration of load, may cause the part under the load between the joints to sink.

A defective bond may appear very good on the face, i.e., the joints on the face may break (See Fig. 141), but there may be no transverse bond. Masons are apt to build up the sides of the wall separately and fill the interior with chips and mortar. The inevitable consequence of this is that the wall consists of two separate slabs on edge, united together only by through stones or overlapping headers at intervals. This should be avoided. As far as possible, stones from the opposite faces should be so laid as to cross each other, thereby adding transverse strength to the wall. This is quite possible in walls of moderate thickness.



Figs. 141, 142:

The elevation in the left-hand figure looks very well, but if there is no transverse bond, as shown in its section on the right, the wall will be weak. "Q" means quoins.

(iii) Through stones used in the work must have a sufficient sectional area throughout their length. As a rule the width

of a through stone must be 1½ times the height, and the aggregate surface, shown by their ends on each face of the wall, must be from ⅛ to ¼ of the surface area. For masonry consisting of courses, the spacing of headers, or through stones, is usually 1.5 m. (5 feet), and these should be laid staggered in successive courses as shown in Fig. 87, page 70.

(iv) The interior of the masonry must be properly packed with mortar and chips, the latter being necessary in types of stone masonry other than ashlar.

(v) The vertical faces of the masonry must be tested with a plumb-rule for their verticality, and the battered faces should be tested with a wooden template and a plumb to ensure that the batter is being given uniformly from bottom to top. (See Fig. 143).

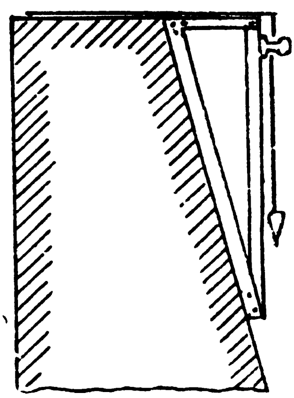


Fig. 143:

Showing how the batter of masonry is tested by means of a mason's wooden square.

(vi) As far as possible, the masonry in the entire length of a wall should be uniformly raised. This increases the pressure on the foundation under the entire length uniformly, and eliminates the danger of unequal settlement. However, if for the time being any part of the wall is to be raised higher than the remainder, the joint should be left in steps so as to allow a proper connection between the old and new work to be made subsequently. (See Fig. 144).

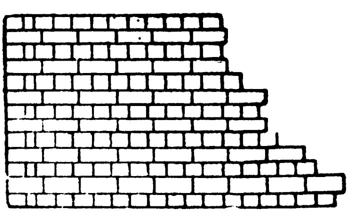


Fig. 144:

Brick masonry, showing how steps are left for proper junction when the wall is extended on the right-hand side.

(vii) The stones to be used in the masonry must be wetted before use so that they do not absorb the moisture from the mortar and thereby reduce its strength.

(viii) In building upon old or dry work, the upper surface should be swept clean and wetted before mortar is spread upon

it, to form a bed for the new work. If dust, etc., is allowed to remain on the upper surface of the old work, the new mortar that is spread will not properly adhere to it, and the joint between the old and new work will not be satisfactory.

(ix) Proper precautions must be taken to see that the work is well watered until the mortar has set. Normally, watering should be done for 15 to 20 days when lime mortar is used, and for 7 to 10 days when cement mortar is used.

(x) All joints on the exposed surface should be raked at least 3 cm. (one inch) deep and pointed with cement.

(xi) No tensile stresses should be allowed in masonry.

Classification of Stone Masonry: The two main types of stone masonry are: (1) Ashlar masonry and (2) Rubble masonry.

Ashlar masonry is made up of squared blocks of stone, tooled to a true face on all sides. The courses of ashlar masonry are uniform in depth which is seldom less than 30 cm. (12 inches). As the surfaces of the stones are perfectly plane, the joints in ashlar work are uniform and thin 1·5 mm. to 6 mm. (1/16″ to ¼″).

According to the quality of dressing on the sides and bed, and the type of surface finish, ashlar masonry is classified as under:

(i) Ashlar Fine.
(ii) Ashlar Rough Tooled.
(iii) Rock or Quarry-faced Ashlar.
(iv) Chamfered Ashlar.
(v) Block-in-course Masonry.

For want of space, it is not proposed to give detailed specifications of the various types of ashlar work. Only the distinguishing features of each type will be given.

Ashlar Fine: In this type of masonry the stones are fine chisel dressed on all beds, joints, and faces, and the thickness of the mortar joint does not exceed 1·5 mm. (1/16th of an inch).

Ashlar Rough Tooled: The beds, joints, and the faces of stones in this class of work are rough tooled. Occasionally the exposed faces of stones have a fine chisel dressed draught all round the edges. As the surfaces of stones coming in contact with each other are rough tooled, the joints are thicker, i.e., 6 mm. (¼th of an inch) thick.

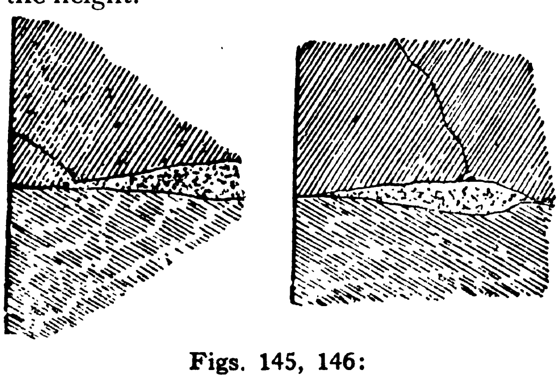
Rock or Quarry-faced Ashlar: This is similar to ashlar rough tooled, except that the exposed surface between the fine chisel-draughted margins is left rough, i.e., quarry-faced. The projections on the face, which are known as bushings, are not allowed to protrude more than 8 cm. (3 inches.)

Ashlar Chamfered: This is similar to ashlar rock-faced except that the exposed edges are chamfered or levelled for a depth of about 3 cm. (one in.).

Block-in-Course Masonry: This is similar to ashlar rough tooled masonry except that the minimum height of the courses specified in this case is smaller than that specified for ashlar work.

Points to be Observed in the Construction of Ashlar Masonry: In addition to the general principles to be observed during the construction of stone masonry discussed on page 82, the following points need careful attention in executing ashlar work.

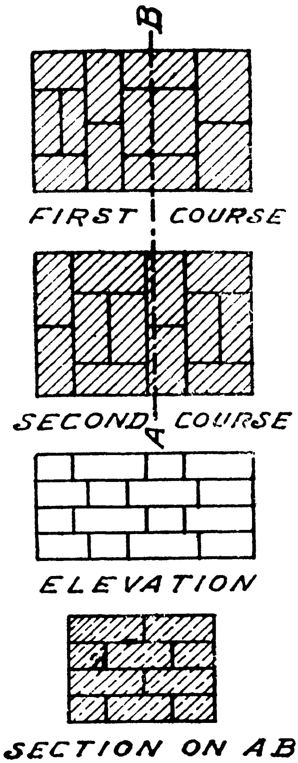
(i) *Rule for the Proportion of Stones:* In order that stones may not break across, no stone of soft material, such as the weaker kinds of sand-stones and granular lime-stones, should have its length greater than three times the height. For harder stones the length may be as much as five times the height. The breadth of softer stones may range from one and a half times to twice the height, and for harder stones it may be as much as three times the height.



Figs. 145, 146:
A flushed joint and an underpinned joint.

(ii) Mortar used for superior descriptions of ashlar work should be a very fine slurry of cement or pure lime mixed with fine sand.

Faces, Beds and Joints: The faces of ashlar masonry may be finished in any one of the ways discussed on pages 78, 79. The joints and beds, though very carefully dressed, should not be too smooth; otherwise their surfaces will afford no key for the mortar, nor offer sufficient resistance to sliding. However, it is important that the surfaces should be "out of winding," i.e., in true planes, and that they should be square to one another. Great care must be taken to see that the bed joints are not dressed hollow. This is often done to show a very fine joint on the face without taking the trouble of carefully dressing the whole surface of the bed. This leads to the entire weight being thrown on to a few points at the edge, and a spall or a piece at the edge is splintered off. The stone is then said to be flushed at this point (Fig. 145). Flushed joints are particularly likely when the stones are not laid on their natural beds.



Figs. 147—150:
Plan of first and second courses of ashlar masonry, showing the bond.
Figs. 149 and 150 represent an elevation and cross-section.

With the same object of saving labour, the middle of the stone is worked slack and underpinned as shown in Fig. 146. The stone is thus supported at the front and the back, and is liable to crack in the middle.

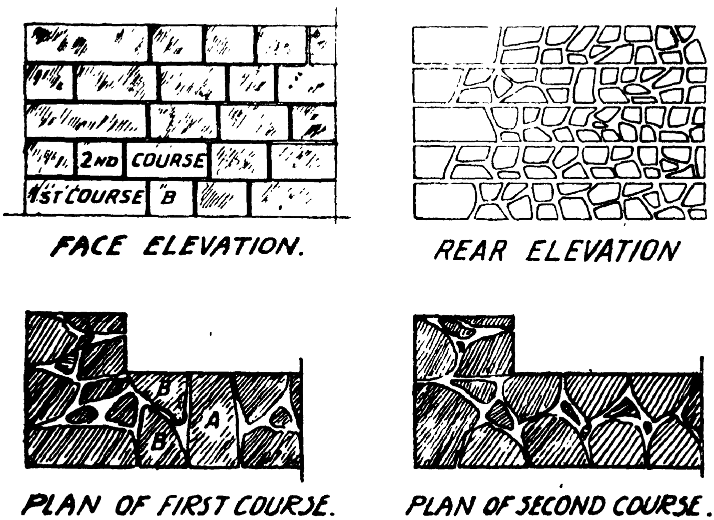
Flushed joints can be guarded against by raking out the face joints for a depth of 2 cm. (an inch) or so, and pointing the joint with fresh mortar after the work has settled.

Bond: As the stones in ashlar work are cut to rectangular blocks, the general directions with regard to bond given on page

82 can be easily followed. The break between the vertical joints in consecutive courses varies according to the nature of the work, from one to one and a half times the depth of the course. In any case the break of joints must not be less than 10 to 15 cm. (4″ to 6″).

The best bond for ashlar work consists of headers and stretchers alternately in the same course. As will be seen later, this arrangement is similar to the flemish bond in brick-work. Two successive courses of ashlar masonry are shown in Figs. 147, 148, and an elevation and section are shown in Figs. 149, 150.

Setting Stones: In setting ashlar work, the stone should first be placed dry in position, to see if it fits well. The stone should then be removed and the upper surface of the lower



Figs. 151—154:
B, B in Fig. 153 are short headers overlapping each other. A is a double-faced through header.

course should be thoroughly cleaned off and wetted. On this a uniform thin bed of mortar should be prepared, and the new block with its bed joint, well wetted, should be laid evenly in its position and settled down by striking it with a mallet.

Rubble Masonry: There are several kinds of rubble

masonry, each known by a technical name, depending upon the regularity or otherwise of the joints, dressing of the edges, thickness of joints, etc.

Broadly speaking, rubble masonry can be classified into two varieties, viz. uncoursed or random rubble masonry, and coursed rubble masonry.

Uncoursed rubble masonry is built with rough stones used without any dressing, except knocking out of occasional inconvenient projections and weak corners. The stones are picked at random from a heap and fitted into the work so as to interlock with each other as perfectly as possible. The interior of the wall is then properly packed with chips and mortar so as to leave no hollows.

Coursed rubble masonry is constructed in horizontal courses which are usually 15 to 20 cm. (6″ to 8″) high. The face stones are rectangular faced, thus making the side joints vertical and the bed joints horizontal.

Rubble masonry is weaker than ashlar or brick masonry. The beds and side joints in rubble masonry are not so carefully dressed, and the strength of the walling depends greatly upon the strength of the mortar and the quality of workmanship. If the latter is not proper, hollows will be left in the wall, and its strength will be considerably impaired.

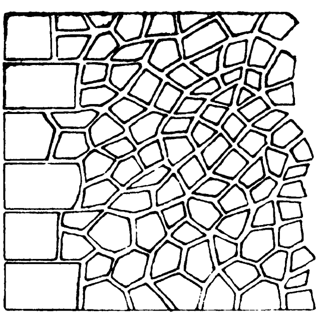


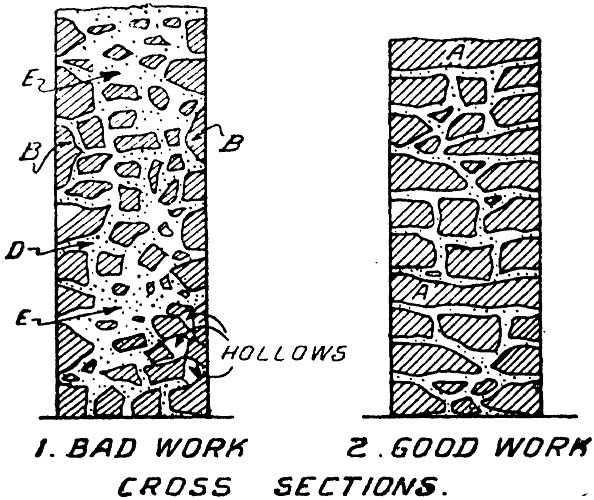
Fig. 155:
Facework of uncoursed rubble masonry.

Special Considerations in the Construction of Rubble Masonry: Face stones for superior classes of uncoursed rubble masonry (usually known as random rubble masonry) should be fairly uniform in size and of a shape approaching a regular polygon. In any case, the height of a stone must never exceed its least horizontal dimension. Stones must be placed on their widest bed so that they may not be crushed or may not act as wedges, and force out the adjacent work. Masons, if left

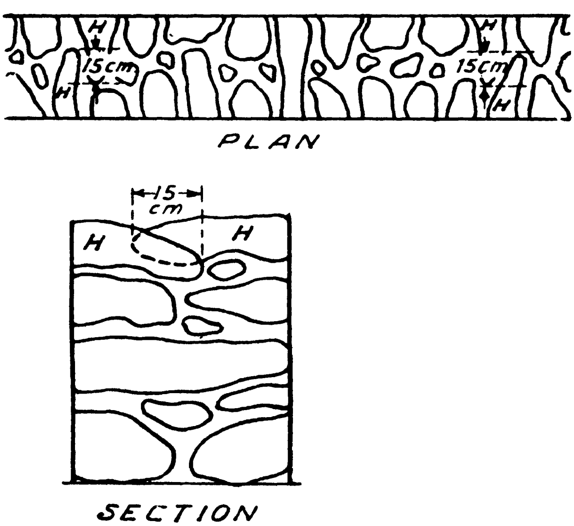
to themselves, will place the face stones like bricks on edge, and fill the interior with chips, frequently leaving large hollow spaces (See Fig. 157) which may or may not be filled even with

Figs. 156, 157:

Vertical section of walls A, A are double - faced headers; B, B, stones laid on edge; they should have been laid on the flat surfaces. D, hollows; E, E, hollows filled with only mortar. There should have been stones in the mortar.



mortar. It should therefore be seen that the face stones tail back sufficiently into the hearting so as to create a good bond between the facing, hearting, and backing (See Fig. 156 and also Figs. 158, 159).



Figs. 158, 159:

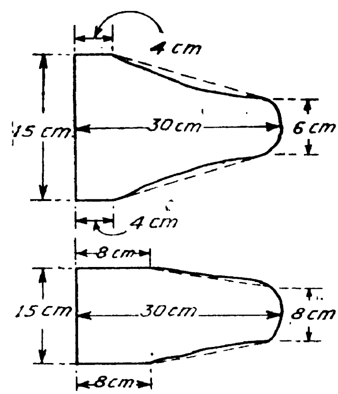
Plan and cross section of a coursed rubble wall, showing through stones and bond stones or headers (HH) whose tails overlap each other by 15 cm. (6 in.) or more.

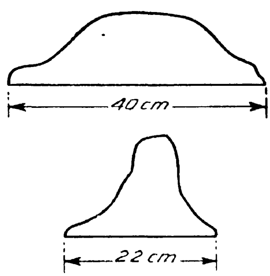
Feather edge face stones (See Figs. 162, 163) make very weak masonry and must never be used.

General principles of maintaining a good bond given on page 82 must be followed, and though it is almost impossible to break joint on every stone, yet long, continuous vertical joints must not be permitted. Through stones or overlapping headers inserted from both faces must be used at a minimum rate of one per square metre (sq. yard) of surface.

Chips should not be allowed in bed joints for setting a stone.

For superior classes of random rubble work, the face stones are so worked as to fit in the work without any packing of small chips or spalls, but for inferior kinds of masonry (uncoursed rubble) the spaces between the stones of irregular shape must be carefully packed with spalls so as to avoid very wide mortar joints.





Figs. 160, 161: Figs. 162, 163:

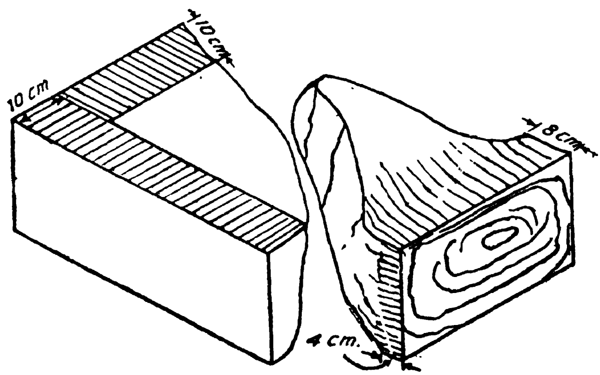
Left:—Plan and side elevation of a good specimen of "khandki" or face stone in coursed rubble masonry.

Figs. 162, 163:

Right:—Plan of feather-edged "khandkis" with insufficient tails.

The width of the face stones for coursed rubble work must never be less than the height of the course. Two-thirds of the number of face stones must tail back into the work for a length equal to their height, and the remaining one-third must do so for a length equal to one and a half times the height. The beds and the sides of the face stones must be at right angles to one

another. The beds and the sides must also be dressed true to a depth equal to 8 cm. and 4 cm. (3″ and 1½″) respectively. (See Fig. 165).



Figs. 164, 165:
A good quoin and a "khandki" respectively.

The vertical joints in successive courses must break on each stone by a minimum length equal to one half the height of the course.

Through stones, or overlapping headers, must be used in each course at an interval of 1·5 m. (5 feet), these being staggered in successive courses.

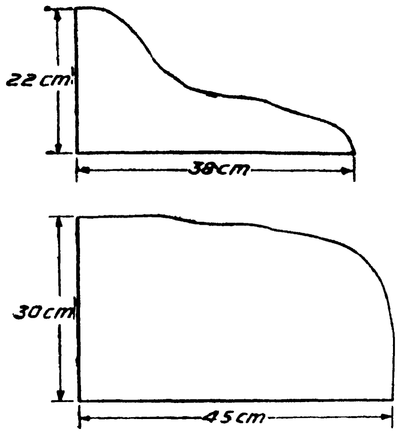
As far as possible, the courses should be of uniform height, but if the height is varied, no course should be thicker than any one below it.

The hearting of both coursed and uncoursed rubble masonry should consist of large flat-bedded stones flushed in mortar and packed well with spalls and chips, where necessary.

Due to the uneven and undressed surface of the stone in rubble masonry greater care and skill are required on the part of the builder to construct exactly a vertical or accurately battered rubble wall. The plumb should, therefore, be used rigorously and frequently.

Corner-stones or Quoins: Corner-stones or quoins in coursed rubble work are usually of the same height as that of the course,

but occasionally the height of the quoin is equal to that of two courses.



Figs. 166, 167: Plans of bad and good corners respectively.

In order that vertical joints on each stone may break, one side of the corner-stone is longer than the other by about 15 cm. (6 in.), and the corner-stones in alternate courses are placed with their longer side on the same exposed face. (See Fig. 155).

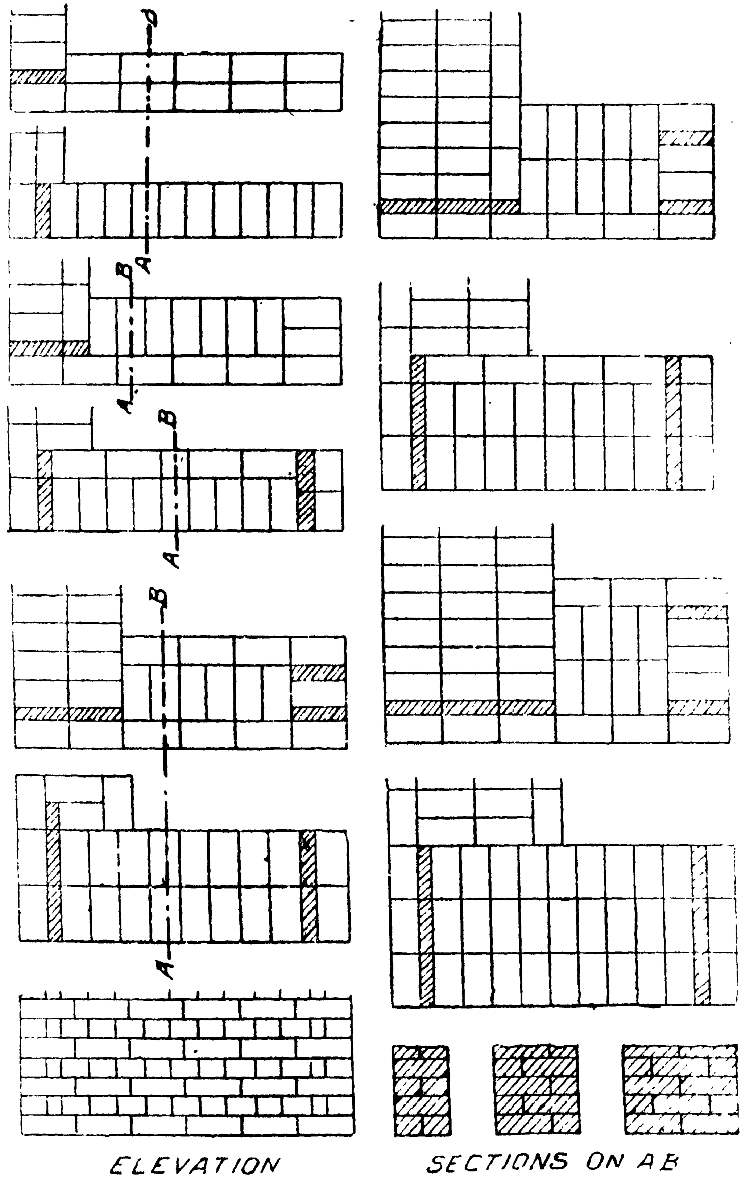
As corner-stones are exposed on two faces, they get no lateral support, and, therefore, their beds must be dressed for at least 10 cm. (4 in.) from the face so as to give them the necessary stability. (See Fig. 164). A bad and a good corner-stone are shown in plan in Figs. 166 and 167 respectively.

Brickwork

Brick masonry may be constructed in cement mortar, lime mortar or mud. Brick masonry in mud is known as *kutcha-pukka* masonry and is frequently used for economy in inferior classes of work. Brick-in-mud masonry, when carefully pointed, lasts practically as long as brick-in-lime masonry, and the repairs required for both these classes of work are more or less the same. Whenever it is contemplated to use brick-in-mud masonry, lime mortar should be used for all work up to the plinth level, for arching, for the top portion of the wall, for corbels, for cornices, and around doors and windows. The destructive agencies to which brick-in-mud masonry is exposed are damp, white ants and rats.

General Principles to be Observed During the Construction of Brick Masonry: Most of the general principles laid down for stone masonry apply to brick masonry also, still they are given here for ready reference.

1. Bricks to be used in the work should be well burnt and of uniform size, shape and colour. Bats must not be used except



Figs. 168-181:

English Bond. Plans of first and second courses of brick walls 1, 1½, 2, 2½ and 3 bricks thick. The hatched bricks are queen closers laid for accomplishing break of joints. The last three figures at bottom are cross sections on AB.

where they are required as closers for creating the necessary bond.

2. The beds of the courses should be as nearly perpendicular as possible to the line of pressure which the masonry has to bear.

3. A systematic bond must be maintained throughout the whole work. Vertical joints must be staggered and continuous in alternate courses.

4. The bricks should be thoroughly soaked in water before they are used in the work. The cessation of the air bubbles coming out of the water in which bricks are immersed, is an indication of complete saturation.

5. Every joint must be thoroughly filled with mortar, care being taken to see that the thickness of the joint does not exceed 1 cm. (1/4 to 1/2 inch.).

6. Unless brick on edge is specified, all bricks must be laid on their proper beds with the frog on the upper side. Bricklayers very often place the brick with the frog at the bottom for saving mortar, of course.

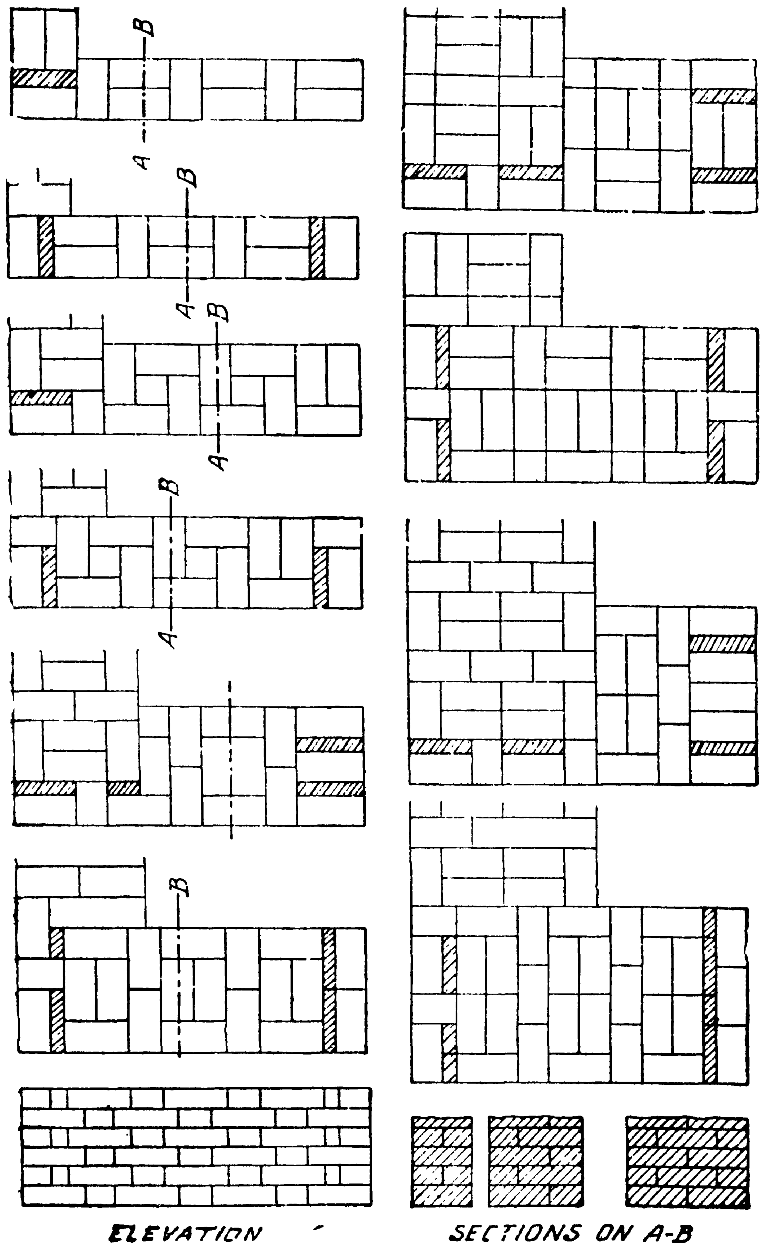
7. All finished work should be kept wet for about 10 days after completion, care being taken to see that the mortar in the joints is not washed away while watering.

8. In constructing long walls, care should be taken to see that the work is uniformly raised throughout its length so as to avoid the probable danger of unequal settlement of the foundations.

Bonds in Brickwork: The importance of maintaining a proper bond has already been dealt with under stone masonry. This point can never be overstressed. Due to uniform size and shape of bricks, a proper bond can easily be maintained by using systematic methods of laying bricks. The advantage of using a systematic method is that the work can be more speedily executed, inasmuch as masons can lay the bricks mechanically, and more masons can be put on a job at a time.

Many bonds for brickwork have been evolved, but the common varieties are (A) the English bond, and (B) the Flemish bond.

English Bond: The following particulars apply to the English Bond:



Figs. 182—195 :
Plans of first and second courses of brick walls in Flemish Bond, 1, 1½, 2, 2½ and 3 bricks thick. Hatched portions show queen closers.

1. The courses are alternately heading and stretching.

2. A closer brick is placed immediately next to the quoin header.

3. In walls, thickness of which is an even multiple of half bricks, the same course will show either headers or stretchers on the inner and outer faces.

4. In walls having a thickness equal to an uneven number of half bricks, the same course will show headers on one face and stretchers on the other.

5. In walls having a greater thickness than 1½ bricks, it will be observed that the external row of bricks are headers or stretchers in the alternate courses; yet those within the wall are all laid as headers. If stretchers are used within the body of the wall, it would cause straight vertical joints.

Thus the number of stretchers is less in proportion as the thickness of the wall increases. This deficiency of the stretchers weakens the wall in the longitudinal direction, and to remedy this, courses of bricks placed diagonally are introduced at intervals, (See Raking Bond.)

6. The number of vertical joints in the heading course is twice the number of joints in the stretching course, and, therefore, the joints in the former are required to be made thinner than those in the latter, approximately in the proportion of 1 : 1·3.

Figs. 168 to 181 show the plans of two courses of brickwork (1 brick, 1½ bricks, 2 bricks, 2½ bricks, and 3 bricks) in the English Bond.

A careful study of these figures will bring out the peculiarities of this bond more clearly.

Flemish Bond: The following features distinguish the Flemish bond.

1. It shows in elevation in every course, headers and stretchers alternately.

2. A header in any course is in the centre of a stretcher in the course below it.

3. Closers are inserted in alternate courses next to the quoin header for breaking the vertical joints in successive courses.

4. In walls having a thickness equal to an uneven number of half bricks, bats are required to be used.

Figs. 182 to 195 show the plans of two courses (1 brick, 1½ bricks, 2 bricks, 2½ bricks and 3 bricks thick walls) constructed in the Flemish bond.

In brief, the comparative merits and demerits of the English and the Flemish bonds are as under:

1. For walls thicker than 1½ bricks, the English bond is stronger than the Flemish bond. For walls 1 brick or 1½ bricks thick, the two bonds have practically equal strength.

2. The Flemish bond has a better appearance on the face because headers and stretchers are alternately used.

3. Where the Flemish bond is used, and where the thickness of the walls is equal to an uneven number of half bricks, bats can be used in the construction, but it requires more mortar.

Occasionally in thick walls a combination of the English and Flemish bonds is used, the former being used for the backing and the latter for the facing. This arrangement combines the advantages of the two bonds, and simultaneously eliminates their disadvantages. This is called Cross Bond.

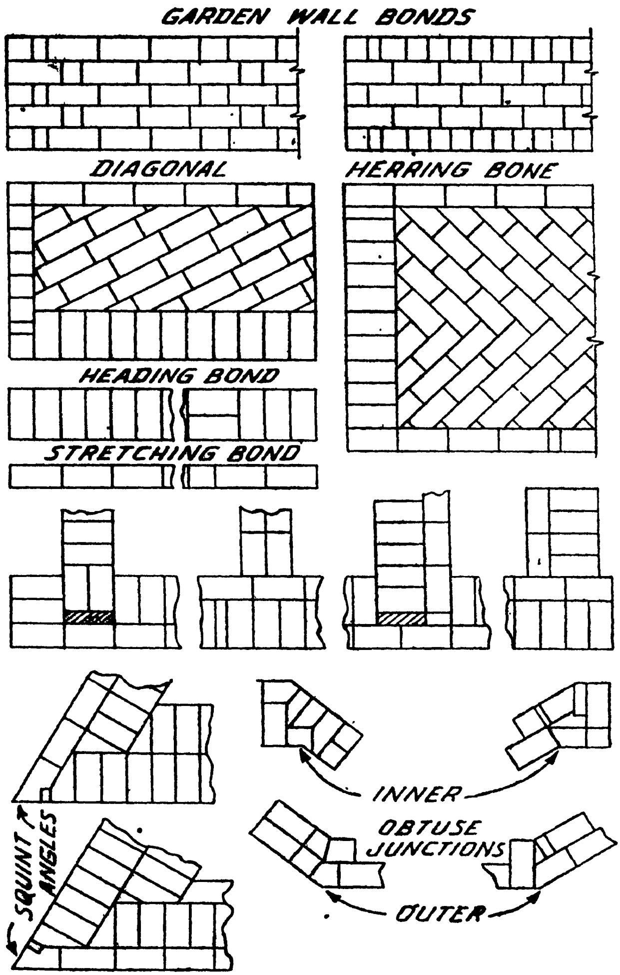
Other Bonds: The following additional bonds which are not in very common use are briefly dealt with here.

1. *Stretching Bond:* This bond is used for walls a half brick thick (such as partitions) and is constructed by laying all bricks as stretchers. (See Figs. 202, 203.)

2. *Heading Bond:* In this bond all bricks are laid as headers on the faces. This bond is mainly used for footings in foundations (Figs. 200, 201.)

3. *Garden Bond:* This bond is used for walls, one brick thick. There are two sub-varieties of this bond, viz. English Garden bond and Flemish Garden bond (See Figs. 196 and 197.) The former consists of one course of headers to three or four courses of stretchers and the latter contains in each course one header to three or four stretchers. The object of using this bond is to minimise the number of headers in order to get a fair face on both sides of a one-brick-thick wall. This would not be possible if the number of headers used is large, because the lengths of bricks are not quite uniform.

4. *Facing Bond:* This bond is used where the facing and backing is made of bricks of different thicknesses. But if bricks of one standard size as tentatively suggested by the Indian Standards Institution, viz. 20 cm. × 10 cm. × 10 cm. are manu-



Figs.
196, 197.
198, 199.
200, 201.
202, 203.
204-207.
208-210.
211-213.

factured and used for facing and backing, the old Facing Bond with bricks of different thicknesses no longer exists.

There is one disadvantage in using bricks of different thick-

nesses for the backing and facing. The number of joints in the backing and facing is different and there is a likelihood of unequal settlement of the two portions, which in their turn, might cause cracks in masonry. But this does not arise with bricks in metric units.

5. *Raking Bond:* There are two sub-varieties of this bond, viz., (a) *Diagonal Bond* and (b) *Herring-bone bond.* In both these types the bricks in the interior of the wall are laid oblique to the face of the wall.

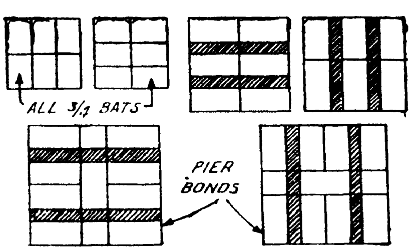
As already mentioned on page 97, courses of raking bond are introduced in thick walls at intervals to increase the strength of the walls in the longitudinal direction. In both kinds of raking bond, alternate courses rake in the opposite directions.

Figs. 198 and 199 show the plans of diagonal and herring-bone bonds.

It should be noted that the diagonal bond cannot be used for walls wider than 1½ bricks and the herring-bone bond can be used only for those thicker than 2½ bricks.

Bond at Junctions of Walls: The usual angle of intersection of walls is a right angle, although occasionally walls do meet at acute or obtuse angles.

When two walls are to be connected, it is absolutely necessary to interlock the masonry of the two walls in such a way as not to leave a straight vertical joint between the two walls.

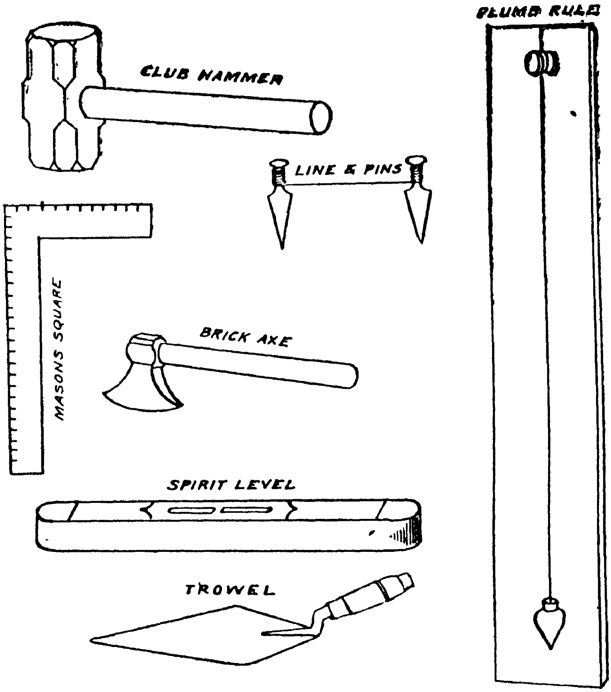


Figs. 214—219:
Plans of first and second courses of brick piers 1½, 2 and 2½ bricks square, showing how queen closers are used to obtain good bond.

In cross walls abutting against a main wall at right angles, this bond is obtained by placing a closer at half-brick distance from the face in every alternate course of the main wall. This arrangement leaves in every alternate course of the main wall a space ¼ brick deep, into which a corresponding projection of the cross-wall fits in.

Figs. 204 to 207 show some typical junctions of walls meet-

ing at right angles, and Figs. 208 to 213 show the junctions of walls meeting at acute and obtuse angles.



Figs. 220—226:
Bricklayer's tools.

Bonds for Brick Piers: Brick piers are usually square or rectangular, and Figs. 214 to 219 show the bonds used for square piers, $1\frac{1}{2}$, 2 and $2\frac{1}{2}$ bricks thick.

The tools used by the brick-layer are illustrated in Figs. 220 to 226.

Method of Constructing Brickwork: At first two extreme corners are constructed for a height of about a foot and the base of the corner is extended in steps. The surfaces of the corners are made perfectly in plumb. Two strings are then stretched between the two corners so as to mark the two external upper edges of the course to be constructed. The face bricks are then laid on a bed of mortar in line and level with strings, and mortar is forced in the space between the face bricks by a trowel. The

bricks in this portion are then arranged one by one in proper bond, and each brick is horizontally moved for a short distance before it is finally placed in its position. This method, which is known as *Parrying,* makes the mortar rise up in the joints and fill all voids.

After the intermediate portion comes in level with the two end corners, the latter are again raised for a height of about a foot, and the process is repeated.

When the wall is raised to a height of about 1·5 m. (4 to 5 feet) the masons can no longer work from the ground, and raised platforms for the masons to stand upon and work are required. These platforms are known as scaffolding. For details of scaffolding see Chapter VI.

Construction of Fire-places: Fire-places are usually required in kitchens and living-rooms of buildings constructed in cold regions.

Fire-places in rooms on various storeys usually stand one over the other, and consequently the chimney flue from the lower rooms has to be carried to one side or the other so as to avoid the fire-place above it. The flues from the lower storeys are, therefore, curved but that from the uppermost is straight. A curved flue is more advantageous than a straight one, inasmuch as it prevents rain or sleet from beating vertically on the fire and impeding down-draughts of cold air. The bends in flues must be properly rounded off, and the flue must in no place be inclined at an angle less than 45° to the horizontal. The inner surface of the flue must be properly pargeted, i.e., plastered with a mixture of one part of cement to three of fine sand to one of cowdung.

Every fire-place should have a separate flue, and the partitions between the various flues should be air-tight as to cut off all communication between the flues. If two flues get connected in any way, and if only one fire is lighted, it will draw air from the other fire-place and the chimney will smoke; moreover, its own smoke might enter the other room, the fire-place of which is connected with the same flue.

The usual size of a flue for a small single fire is 20 cm. × 20 cm. (9″ × 9″) for a single ordinary fire-place the size may be 30 cm. × 20 cm. (14″ × 9″); and for a large kitchen range, 30 cm. × 30 cm. (14″ × 14″) is common. It should be noted

that the smaller the flue and the greater the height, the more rapid is the draught and the less likely is the chimney to smoke.

A fire-place generally requires greater depth than can be provided in the thickness of a wall. It is, therefore, accommodated in a projection known as a chimney breast. When a fire-place is located in an external wall, the projection may be conveniently made on the outside so as to lose no useful space in the room. In other cases the projection is provided on the inside.

It is convenient to gather all the flues from the fire-places in a building and group them in a stack, which is carried sufficiently high above the roof, and is then covered with a concrete or stone slab so as to prevent rain or snow from getting access to the flues. The smoke outlets are kept in the side walls of the stack.

Fire-places in Rooms With Timber Floors: Special precautions are necessary where a fire-place is to be provided in a room with a timber floor so as to avoid the proximity of timber to the fire. The construction on the ground is as follows:

Fender walls 10 cm. or 20 cm. (4½ in. or 9 in.) thick are constructed all round the fire-place at a prescribed distance, or at a greater distance, as may be considered necessary. A wall-plate of timber embedded in these fender walls supports the end of joints abutting against the fire-place. The portion enclosed by the fender walls and the main wall of the building is filled with hard core of fire-proof material. It is advantageous to use weak cement concrete, the surface of which can be conveniently used for bedding the stone slab. (See Fig. 227).

For upper floors the arrangement of fire-places is different. The floor is trimmed so as to form an opening in which the fire-place is to be located. The size of the opening is determined with due regard to the fact that no timber embedded in the wall should be within 30 cm. (12″) of any flue. The opening has to be covered with some fire-resisting material so as to support the hearth-stone. This is managed either by turning a half-brick arch springing from the main wall on one side and the trimmer on the other, or by laying a reinforced concrete slab supported in a similar manner. Figs. 227 and 228 show both these alternatives in sections. For trimming of floors, see Chapter XIII.

In India fire-places are not commonly required except at

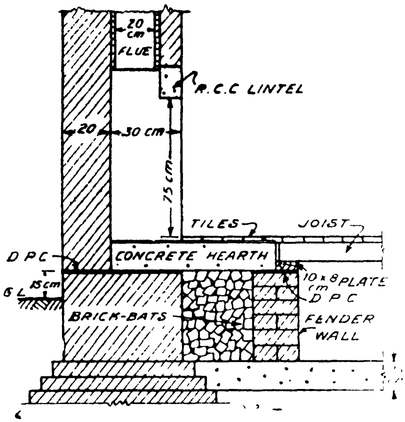


Fig. 227:
Vertical section through a fire-place on ground floor.

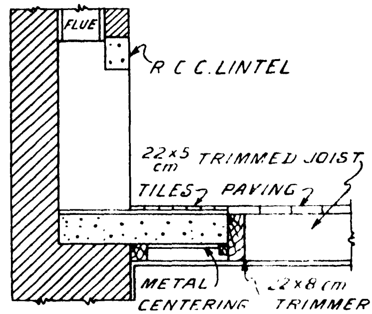
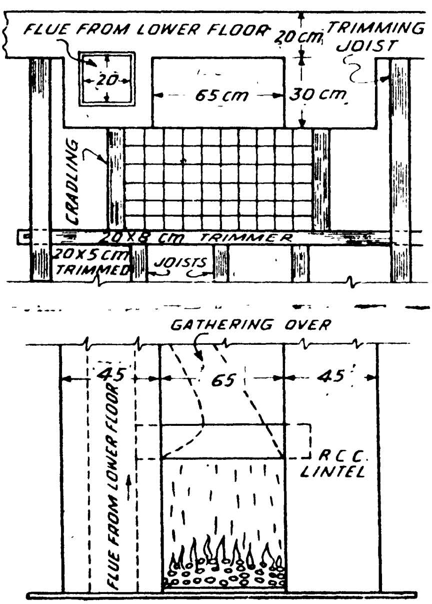
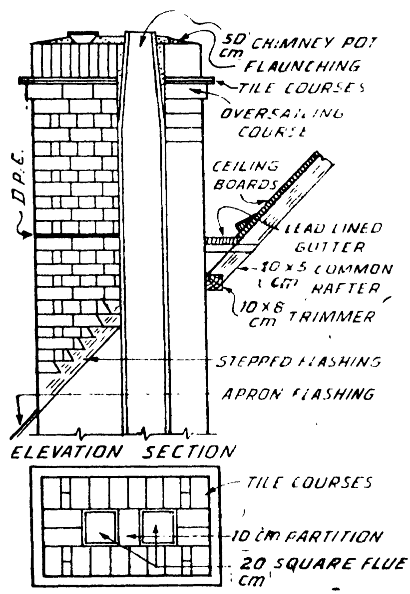


Fig. 228:
Vertical section through a fire-place on upper timber floor.

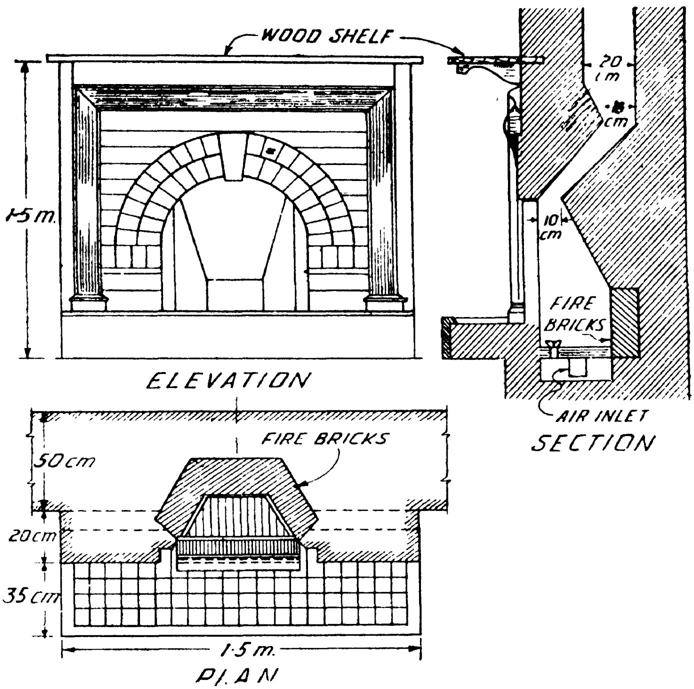


Figs. 229, 230:
Plan and elevation of a fire-place on an upper timber floor.



Figs. 231, 232:
Top—Sectional elevation of a chimney stack showing different parts and lead flashing to drain off rain-water.
Bottom—Plan or a horizontal cross section of a chimney stack.

some of the hill stations and a few places in North India during the winter season, and they are, in most cases, built on the ground floor.



Figs. 233—235:

Top Left—Elevation of an Indian type fire-place.

Top Right—Vertical section. *Bottom*—Plan.

A type suitable for Indian conditions is illustrated in Figs. 233 to 235.

Thickness of Brick Walls: For making the structure strong and stable, the thickness of walls must be sufficient to withstand the forces acting on the wall, viz., (a) Dead load of the wall, (b) Live load of the floors, and (c) Wind load. Of these, the first two are vertical and the last one is oblique. The vertical load, when acting along the centre line of the wall, is known as a concentric load and produces uniform compression in the material constituting the wall. An eccentric load has its point of application away from the centre line, and it produces greater com-

pression on the edge to which the load is nearer and smaller compression on the other edge. The values of the minimum and maximum compression can be calculated by the following formula as already explained on page 23.

$$\text{Stresses at the extreme edges} = \frac{P}{t}\left(1 \pm \frac{6e}{t}\right)$$

where P = Load in tons per meter of wall

t = Thickness of wall in cm.

e = Eccentricity of the load, i.e. the distance of its point of application from the centre line of the wall.

It will be observed from the formula given above that as the eccentricity goes on increasing, the magnitudes of the maximum and the minimum stresses correspondingly increase and decrease respectively, until ultimately when e equals $\frac{t}{6}$ the minimum stress becomes zero. Now, if the eccentricity is further increased the sign of the minimum stress becomes negative; in other words, tensile stresses are set up at one edge. In any kind of masonry, tensile stresses must be avoided, and therefore in no case should the eccentricity be allowed to exceed the limit of $\frac{t}{6}$. This is one criterion for determining the thickness of a wall. The second is the maximum stress at the other edge which must not be allowed to exceed the safe permissible limit specified for the material of the wall.

Effect of Wind Pressure on Walls: The effect of wind pressure on walls is to produce a bending and sliding action on the wall.

Bending produces tension on the outer face and compression on the inner face, and sliding produces shear stresses. The tensile and compressive stresses can be calculated by the following formula:

Tension or compression per sq. cm.

$$= \frac{\text{Bending moment in kg. cm.}}{\frac{t^2}{6}}$$

In testing the stability of a wall, the cumulative effect of stresses due to the vertical load and bending should be taken into account.

In designing walls of ordinary buildings it is neither possible nor necessary to calculate theoretically the required thicknesses of various walls. Tables giving the minimum thicknesses of walls for different kinds of buildings are included in the bye-laws of various municipalities and other authorised local bodies dealing with similar matter, and the thicknesses of walls provided according to these tables are usually safe. These thicknesses are based on past experience and can also be corroborated by theory. The thicknesses prescribed by the Bombay Corporation are given in Tables Nos. 12 and 13.

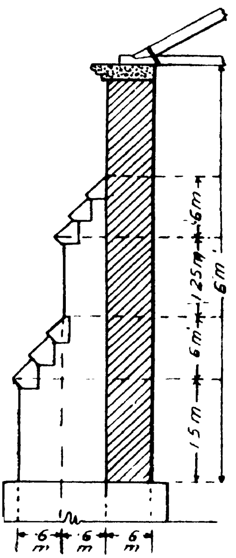


Fig. 236:
A Buttress.

It will be seen from the table that, for the same height, the greater the unsupported length of the wall, the greater is the thickness required. This shows that cross-walls considerably add to the strength of a long wall. The same effect can be produced in a long wall without any cross-walls by providing small thickened portions in the wall at intervals. These thickened portions are known as buttresses or pilasters. (See Fig. 236.) Buttresses or pilasters can be conveniently located at points where the wall has to support heavy concentrated loads such as floor beams or trusses.

Hollow Walls: Hollow walls, which are also known as *Cavity Walls,* are made up of two separate parts constructed parallel to each other, with a continuous cavity 5 cm. to 10 cm. (2 in. to 4 in.) wide between them.

These walls are very efficient in preventing the dampness of the outside atmosphere from getting access to the inside of a room, and also help in keeping the temperature inside the room least affected by the atmospheric changes outside.

Hollow walls usually consist of one thick main portion

*TABLE No. 12

THICKNESS OF MASONRY WALLS OF DOMESTIC BUILDINGS

Thickness of wall in cm. based on brick size = 20 cm. × 10 cm. × 10 cm.

Storey	Height above Plinth m.	Length m.	Basement cm.	Floors 1st	2nd	3rd	4th	5th	6th	7th	8th	9th
1	3·25	Unlimited	30	20								
1	2·50 & 5·0	For a height of 2.5 m.	30	30								
		For the remaining height		20								
1	7.5	Under 10	40	30								
2	7·5	Under 10	40	30	20							
2	7·5	Over 10	40	30	20							
3	10·7	Under 10	40	30	30	20						
3	10·7	Over 10	40	40	30	20						
4	13·7	Under 10	40	40	30	30	20					
4	13·7	Over 10	50	40	40	30	20					
5	16·7	Under 10	50	40	40	30	30	20				
5	16·7	Over 10	50	50	40	40	40	30				
6	20	Under 10	50	50	40	40	40	30	20			
6	20	Over 10	60	50	50	40	40	30	20			
7	23·5	Under 10	60	50	50	40	40	30	30	20		
7	23·5	Over 10	60	60	50	50	40	40	30	20		
8	26·8	Under 10	60	60	50	50	40	40	30	30	20	
8	26·8	Over 10	70	60	60	50	50	40	40	30	20	
9	27·4	Under 10	70	60	60	50	50	40	40	30	30	20
9	27·4	Over 10	70	70	60	60	50	50	40	40	30	20

TABLE No. 13

THICKNESS OF MASONRY WALLS FOR PUBLIC OR WAREHOUSE TYPE BUILDINGS

Thickness of wall in cm. based on brick size = 20 cm. × 10 cm. × 10 cm.

Storey	Height above Plinth m.	Length m.		Basement cm.	Floors 1st	2nd	3rd	4th	5th	6th	7th	8th	9th
1	7·5	Unlimited		30	30								
2	7·5	Unlimited		30	30	30							
3	10	Under	15	40	30	30	30						
3	10	Over	15	40	40	30	30						
4	13·5	Under	15	40	40	30	30	30					
4	13·5	Over	15	50	40	40	30	30					
5	16·75	Under	15	50	50	40	40	30	30				
5	16·75	Over	15	50	50	50	40	30	30				
6	20	Under	15	60	50	50	40	40	30	30			
6	20	Over	15	60	60	50	40	40	30	30			
7	23·5	Under	15	60	60	50	50	40	40	30	30		
7	23·5	Over	15	70	60	60	50	50	40	30	30		
8	26·8	Under	15	70	60	60	50	50	40	40	30	30	
8	26·8	Over	15	70	60	60	50	50	50	40	30	30	30
9	30	Under	15	70	70	60	60	50	50	40	40	30	30
9	30	Over	15	70	70	70	60	50	50	40	40	30	30

which supports the weight of the floor and roof, and the other thin portion, which is usually only 10 cm. (4½") thick.

Walls With the Thin Portion Inside: This method possesses two disadvantages, but is occasionally resorted to when the main thick portion is of stone.

Firstly, the bulk of the wall is exposed to damp, and the moisture soaks to within 15 to 20 cm. (7 or 8 inches) of the interior of the building. Secondly, the span of the roof is also increased, thereby adding to the cost of the building.

However, there is one advantage in having the thick portion outside, inasmuch as it permits of deeper reveals being formed for the doors and windows.

Walls With the Thin Portion Outside: By this method the damp is effectually intercepted by the air-space kept out of the great portion of the wall and at a considerable distance from the inside.

As the span of the roof is not unnecessarily increased, it can be constructed more economically. However some people consider the stretching bond of the outside thin portion as unsightly, but this can be improved by introducing false headers. Moreover, in this case, there is some difficulty in constructing deeper reveals in a solid manner without their helping the communication of damp to the inside.

The two portions of the wall are interconnected by bonding bricks or metal ties as shown in Fig. 237. It should be noted that the higher portion of bond brick should be placed on the inside so as to prevent the moisture from running along the brick to the inside of the wall.

Sometimes, ties of wrought iron are used, as shown in Fig. 241, with a twist or a bend in the centre to cut off the passage of moisture along the tie.

Where hollow walls are to be used, they usually start from a damp-proof course of asphalt, slate, or lead at the floor level. However it is preferable to continue the hollow two or three courses below the floor so that the moisture accumulating in the air space can be efficiently drained without affecting the interior of the building. (See Fig. 237).

When lintels of doors and windows occur in hollow walls, a special arrangement is necessary to prevent the moisture in the air-space above the lintel from getting access to the door head. This arrangement consists in building on the inside of the 10 cm.

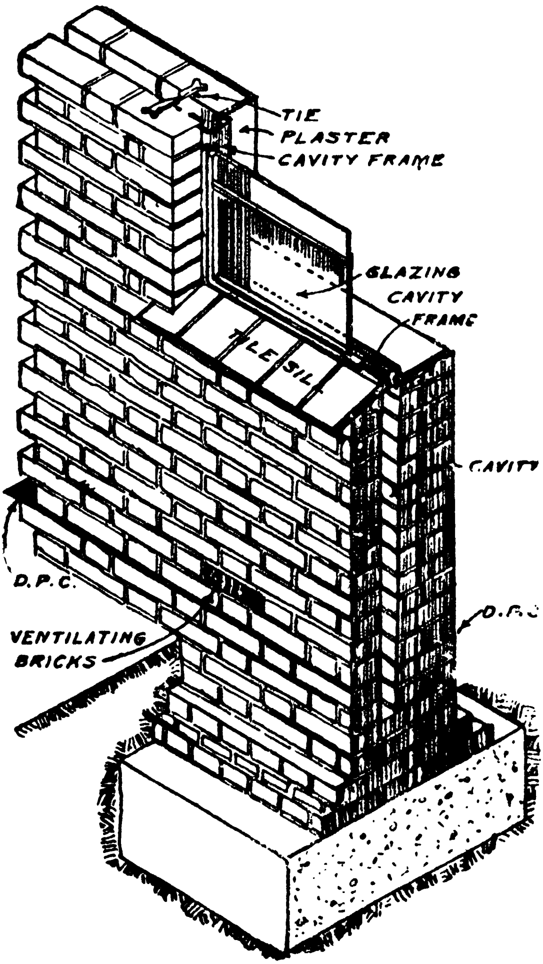


Fig. 237:

Isometric vertical section through metal window sill of a hollow brick wall with thin skin outside. The cavity frame closes the gap round the frame. The D.P.C. is laid on the top of the second course above bottom of cavity. The latter is ventilated.

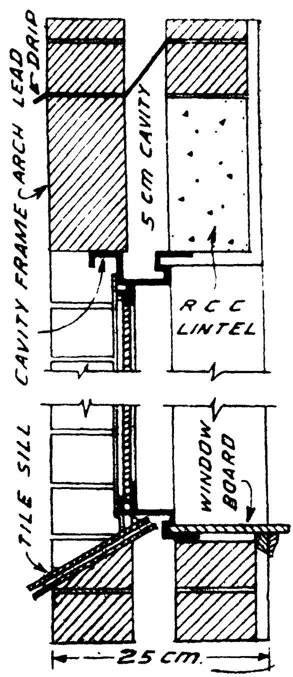


Fig. 238:

Vertical section through window sill and head of a hollow wall with both skins of equal width. Note the cavity frame and the lead gutter and drip.

(4½″) thick exterior wall a lead sheet. The lead sheet may be 12 cm. (5″) wide out of which 5 cm. (2″) may be built in the exterior wall joint, the remaining projecting portion being formed into a gutter about 5 cm. (2″) wide and 2 cm. (1″) deep. The gutter is made to extend about 5 cm. (2″) on either side of the opening so as to lead the water clear of the door or window frame.

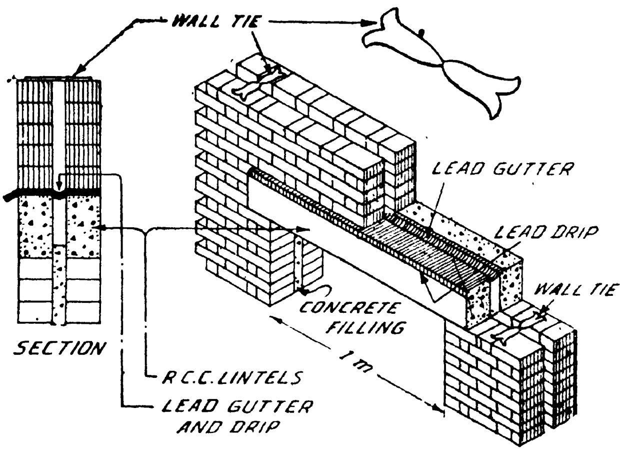


Fig. 239: *(Right)*

An isometric vertical section through window head of a cavity wall. The cavity round window is filled with 5 cm. (2 in.) concrete. Note the lead gutter and drip.

Fig. 240: *(Left)*

Section of a cavity wall.

Fig. 241:

An enlarged view of a wall tie.

Drystone Masonry: Drystone masonry is ordinary rubble masonry without any mortar.

It is used for compound walls, retaining walls, in cuttings, toe walls supporting high embankments, breast walls, pitching slopes of channels and earthen dams which are likely to be scoured.

Out of these structures, retaining walls, breast walls, and pitchings are important, and these will be dealt with in detail.

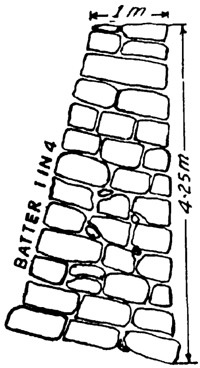


Fig. 242: Drystone retaining wall.

Drystone Retaining Walls: Utmost care is required in the selection of stones of the proper shape and size and in the bounding of the whole work, as the stability of these walls entirely depends on these two factors, there being no mortar to cover the defects of workmanship and those arising from an improper choice of materials.

For these reasons, it is the best plan to collect at site all the required materials, and to put the earth filling at the back after a few feet of the wall are constructed and approved. The correct section of the wall depends on the quality of workmanship, the type of material to be supported, and the height. However, roughly speaking, the top width of the retaining wall should be kept at a minimum of 60 cm. (2 ft.) and the face batter 1 in 4, or 1 in 3, the latter being used for walls higher than 3 m. (10 ft.) As a rule, no drystone retaining wall should be constructed of a height greater than 6 m. (20 ft.) In cases, where the height of the embankment is greater than this, the top 6 m. (20 ft.) may be made up of drystone masonry, but the portion below this must be constructed in lime or cement mortar.

The beds of the courses must be laid perpendicular to the face batter, and all other precautions as to the proper bonding of the work detailed under rubble masonry must be taken.

Occasionally the interstices of drystone walls are filled with shingle or mud, and the face is pointed with cement mortar. In such a case, numerous weep-holes must be left in the wall to drain the water from the filling behind. It should be observed that the weep-holes extend throughout the thickness of the wall and do not get choked up in the rear. The usual practice is to leave a stick in the weep-hole till the completion of the work. When the engineer inspects the work, he pulls out the stick and tests the length of the weep-hole.

Breast Walls: The main function of a breast wall is to protect the slopes of *cutting* in natural ground from the action of weather, and incidentally they have to support some pressure of earth behind. Fig. 243 illustrates the functions of a breast wall and a retaining wall. The latter retains or holds a filling or embankment.

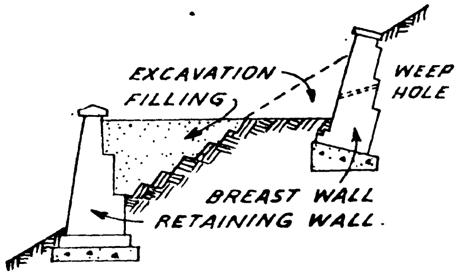


Fig. 243:
The figure shows the difference between a retaining wall and a breast wall.

The section of a breast wall is very much dependent on the soil to be protected and the slope of the cutting. In some cases, the section adopted has a top width of 60 cm. (2 ft.) and a face batter of 1 in 2 and a back batter of 1 in 3 (See Fig. 245).

Most soils can stand a steep slope immediately after they are cut, but a little exposure to weather makes the soil crumble and fall. It is, therefore, necessary that breast walls be constructed as soon after the cutting is made as is possible.

Water should not be allowed to get access to the back of the wall, and any interstices which exist should be filled either with puddle or small gravel.

As in the case of retaining walls, the beds of the courses must be laid perpendicular to the face batter and the work must be properly bonded.

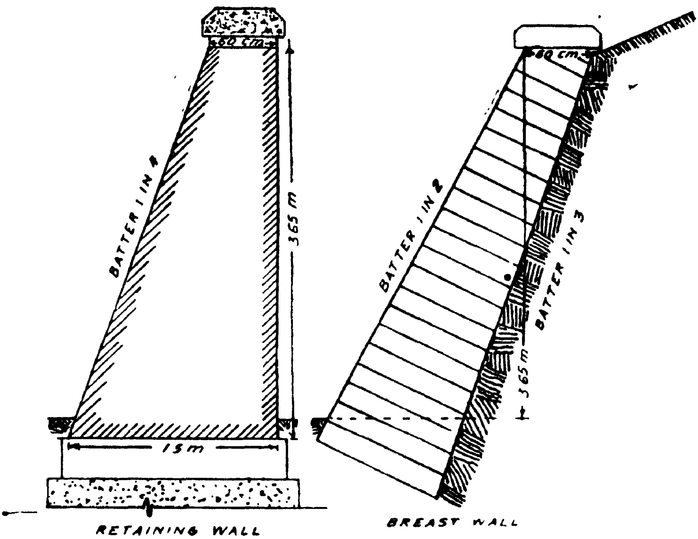
Pitching: Pitching is a stone lining to protect earth surface from the scouring action of water. When the slope of the cutting is fairly flat, it is sufficient to line the face with a uniform thickness of drystone work. The thickness varies according to the requirements, the minimum being a foot and the maximum about two feet. Drystone pitching is often pointed with lime or cement mortar. In constructing pitching, stones should be properly fitted in so as to leave no large gaps between adjacent stones.

As already mentioned, pitching is many times used on slopes of channels and dams.

Masonry Retaining Walls: The function of retaining walls is to retain earthen *embankments.* They are of common occur-

rence in the construction of cellars, hill roads, and bridges, the wing walls and abutments of which, are nothing but retaining walls. (Fig. 244).

If a mass of earth is left exposed to weather, the sides will slip and will gradually attain a stable slope. The inclination to the horizontal of this stable slope is termed the natural angle of repose of the material. ‡



Figs. 244, 245:
A masonry retaining wall and a breast wall.

If an attempt is made to hold the material at a steeper slope than the angle of repose, it exerts lateral pressure on the structure artificially erected to retain the material, and such a structure must be strong enough to withstand this force.

There are different theories advocated for the estimation of the magnitude and direction of the lateral pressure exerted by retained soils, but each one of them is based on certain assumptions.

‡ This angle of repose is taken to correspond to the angle of internal friction of the material, i.e., if "μ" is the coefficient of friction of the soil, and "ϕ" its angle of repose, μ is taken equal to tan ϕ. Experiments, however, show that the angle of friction is about 25% greater than the angle of repose, and some authorities recommend that in all formulæ of soil pressure, the angle of internal friction should be used in place of the angle of repose.

Different Theories of Earth Pressure: Discussing the various theories in detail is outside the scope of this volume, and it is proposed to give here only the results obtained by the important theories and summarize the assumptions made in each.

Rankine's Theory: Rankine's theory is based on the principle of stress distribution in a rigid body, i.e. on the theory of conjugate pressure. The soil is assumed to consist of granular particles without any cohesion, and consequently the direction of pressure is always parallel to the surface slope of the soil.

The following formulae can be derived by this theory:

Case 1. Surface of soil horizontal. Horizontal pressure per sq. m. at a depth h m. below the surface

$$p_h = w \times h \times \frac{1 - \sin\phi}{1 + \sin\phi}$$

where w = Weight of soil per kg./m.^{3} and

ϕ = Angle of repose of the soil.

Total horizontal pressure on a wall h m. high per m. run

$$= P$$

$$= \tfrac{1}{2}\, w\, h^2 . \frac{1 - \sin\phi}{1 + \sin\phi}$$

(See Figs. 246, 247).

The distribution of pressure is triangular, and therefore, the point of application is at a height equal to $\frac{h}{3}$ from the base.

Case 2: Earth sloping at an angle α to the horizontal. (See Fig. 247.) In this case the lateral pressure p_h at a depth h m. below the surface is given by the formula,

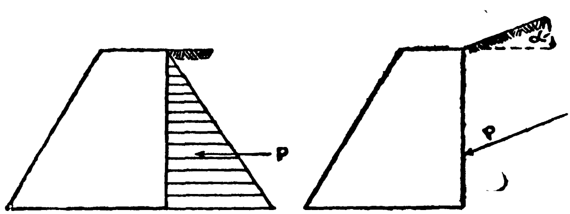
$$p_h = wh \cos\alpha \, \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}$$

and acts in a direction parallel to the surface slope. The total pressure, P, which also acts in the same direction at a point $\frac{h}{3}$ from the base, is given by the formula,

$$P = \tfrac{1}{2}\, wh^2 \cos\alpha \, \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}$$

Coulomb's Wedge Theory: This theory propounds that the plane of rupture bisects the angle between the vertical plane through the heel and the plane of natural slope, and the wall is subjected to the pressure exerted by the sliding prism enclosed between the plane of rupture, the vertical plane through the heel, and the top surface of the soil.

The results obtained by this theory with the back of the wall vertical and the top surface of the soil horizontal are identical with those obtained by Rankine's theory and the total earth pressure $P = \frac{1}{2} wh^2 \frac{1 - \sin \phi}{1 + \sin \phi}$ with its points of application at a height $\frac{h}{3}$ from the base.



Figs. 246, 247: *Left*—A wall to retain earth with a horizontal top surface. *Right*—A wall to retain earth with surcharged earth.

Dr. Scheffler's Theory: According to this theory the friction of earth on masonry is taken into account as well as the cohesion in the mass of earth, and therefore, the resultant pressure is taken to act at an angle ϕ to the horizontal, with its magnitude increased to P sec ϕ where P is the total horizontal pressure on the vertical face according to the wedge theory and ϕ is the angle of friction. It is, therefore, obvious that the

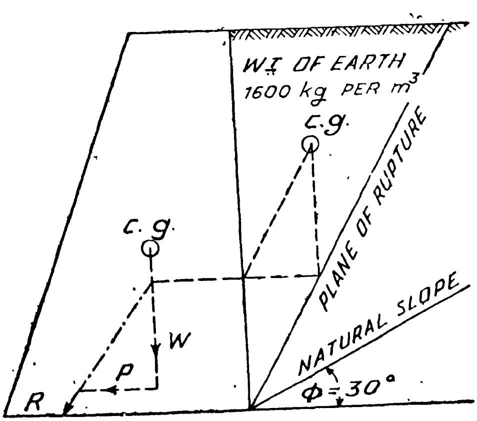


Fig. 248:
Section of a retaining wall illustrating Coulomb's theory of earth pressure, surface of backing horizontal.

magnitude of the pressure is increased but the direction makes an angle ϕ with the horizontal, with the point of application remaining the same viz. at $\frac{h}{3}$ from the base. Therefore, in spite of the increase in the magnitude of the pressure, the overturning moment is reduced and is less than that obtained either by Rankine's theory or the Coulomb's Wedge theory.

Example 1: Calculate the maximum thrust intensity and total pressure on a retaining wall 5 m. high with a vertical back and level earth surface, if it retains moist earth weighing 1550 kg./m.^{3} with an angle of repose of 30°.

Solution: p = equivalent fluid pressure

$$p_{max} = wh \frac{1 - \sin\phi}{1 + \sin\phi} = 1550 \times 5 \times 1/3$$
$$= 2583 \cdot 33 \text{ kg./sq.cm.}$$

$\therefore$ Total pressure on the wall per meter length is

$$P = \frac{p}{2} \times h \times 1 = \frac{2583 \cdot 33}{2} \times 5$$
$$= 6458 \cdot 33 \text{ kg.}$$
$$= 6 \cdot 458 \text{ tonnes acting at } \frac{h}{3} = \frac{5}{3}$$
$$= 1 \cdot 67 \text{ m. from bottom}$$

Example 2: A retaining wall 4 m. high has to resist a thrust of moist earth with its surface sloping at 15° above the horizontal. If $\phi = 30°$, calculate the total horizontal pressure per vertical running ft. of the wall.

Solution: Here $p = wh \cos\alpha \times \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}$

$\cos 15° = 0 \cdot 966$ and $\cos 30° = 0 \cdot 857$

$$p = 1550 \times 4 \times 0 \cdot 966 \times \frac{0 \cdot 966 - \sqrt{0 \cdot 966^2 - 0 \cdot 857^2}}{0 \cdot 966 + \sqrt{0 \cdot 966^2 - 0 \cdot 857^2}}$$
$$= 6200 \times 0 \cdot 966 \times 0 \cdot 363$$
$$= 2175 \text{ kg./m.}^2$$

$\therefore$ The total pressure

$$P = \frac{p}{2} \times h \times 1$$
$$= \frac{2175}{2} \times 4 \times 1 = 4350 \text{ kg. acting at } 15°$$

$\therefore$ P horizontal $= 4350 \times 0{\cdot}966$
$= 4202$ kg. per meter length.

Conditions of Stability of Retaining Walls: In order that a retaining wall shall be stable, the following three conditions must be satisfied:

1. The maximum intensity of pressure should not exceed the safe compressive resistance of the material of which the wall is built, or the material on which it is founded.
2. There should be no tension in any part of the masonry.
3. The horizontal component of the pressure must not be more than half the resistance of the masonry to sliding on any joint.

Methods of Testing the Stability: (Note.—*The stability can be tested at any horizontal section; but with uniform batter, it will usually suffice to test the bottom-most section)*

Determine the weight and C. G. of the masonry and the weight and C. G. of the soil resting on the inside batter, if it is provided. Denote these by w_m and w_s and find out the magnitude and direction of the combined weight. Compound these weights with the lateral earth pressure as calculated by any one of the theories previously discussed, and denote the resultant by *R*. Find out the point of application of the resultant at the base, and the angle which it makes with the normal to the base i.e. the angle with the vertical. (Vide p. 22.)

The distance of the point of application from the centre of the base is known as the eccentricity, which is usually denoted by *e*. The maximum and minimum compressive stresses are given by the following formulae:

$$P_{max.} = P\left(1 + \frac{6e}{b}\right)$$

$$P_{min.} = P\left(1 - \frac{6e}{b}\right)$$

where $P_{max.}$ = maximum compressive stress.
$P_{min.}$ = minimum compressive stress.
P = Average compressive stress.
$= \dfrac{\text{Total vertical weight}}{\text{Area of the base}}$
e = eccentricity
d = width of the wall at the base.

To satisfy the first condition, the maximum pressure, $P_{max.}$ must be within the safe permissible limit of compressive stress for the material in the wall and the foundations.

It will be observed from the formulae giving the maximum and minimum pressures, that the minimum pressure becomes zero when $e = \frac{1}{6} b$. If e is more than this, the stress at the heel becomes negative, i.e. tensile, which is not permissible according to the second condition of stability. Therefore, the maximum permissible eccentricity is $\frac{1}{6}$ b, or, in other words, the resultant must cut the base *within the middle third.* This will fulfil the second condition of stability.

To satisfy the third condition, the angle between the resultant and the normal to the base must not be more than half the angle of friction.

(NOTE.—As the actual earth pressure is less than the pressure calculated according to any of the theories, some authorities consider it safe enough to allow the resultant to cut the base up to one-fifth the length of the base from the toe. Experience shows that walls constructed on this principle have stood quite well.

Retaining Walls of R. C. C.: R. C. C. retaining walls are much cheaper and lighter and yet stronger than masonry walls mainly for the facts that (i) the steel reinforcement allows ten-

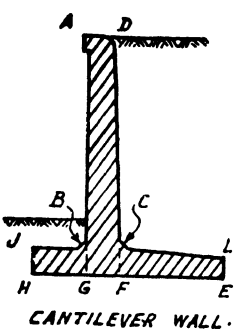


Fig. 249.

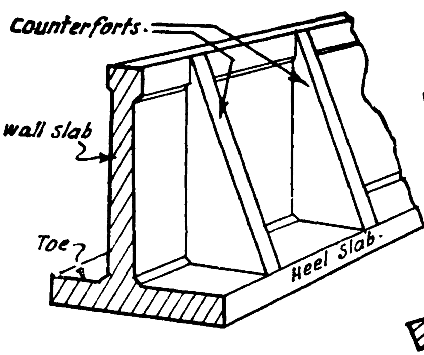


Fig. 250.

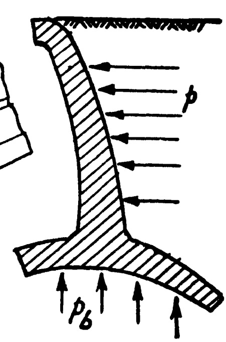


Fig. 251.

sion to be resisted, (ii) the superincumbent load of earth on the heel helps in resisting the over-turning moment, and (iii) the long base offers a larger frictional surface to resist sliding.

There are two types: (1) The cantilever wall, (Fig. 249) in which (a) the stem *ABCD* subjected to horizontal thrust of the mass of earth behind, is designed as a cantilever, (b) the heel *EF* also designed as a cantilever supports the mass of earth above it and resists the upward reaction of the soil below, and (c) the toe, *GH,* also subjected to upward reaction of soil is also designed as a cantilever.

The tendency of these parts to bend under the various forces is shown in Fig. 251.

(2) The other type (Fig. 250) consists of a vertical wall, supported by buttresses, or counterforts at intervals. The wall is designed as a continuous slab held, or supported at its upper (i.e. inner) surface by the counterforts.

Practical Hints on Masonry Construction

(1) If bricks are used in underground work, such as foundation, drainage, manholes, cellar walls, etc., hard, impervious bricks, rather slightly overburnt, than underburnt, should be used. Their appearance and regularity of shape should receive a minor consideration.

(2) Surfaces of wood work such as of doors, windows, wall plates, rafters, trusses, etc. which are to lie in contact with or are to be embedded in masonry or concrete, should receive a coat of creosote or hot coal tar.

(3) If lime is used for plastering inside walls of buildings, the jambs of doors and windows should be plastered with a mortar gauged with a little cement as they are likely to be constantly subjected to wear and tear with every opening of the shutters with a bang.

(4) Small piers between grouped windows, half-brick trimmer arches and courses of chimney stacks, shafts or parapet walls above the roof should be executed in cement mortar.

(5) In corbelling with bricks, the projection of courses should never exceed ¼ brick length (5 cm.) A lesser projection is advisable when great strength is required.

(6) Oversail when possible to support the edges of concrete floors and to receive plates, etc. to avoid building into walls.

(7) *Arches:* (a) Arches of large span, however well bonded, should be built in hydraulic mortar, or cement gauged

mortar (1 : 1 : 6). (b) Half brick rings should never be used in spans exceeding 8 m. (25 ft.) (c) When an arch of whatever span occurs near the end of a wall, provision of a mild steel tie rod should be made for the thrust. It is a fallacy that semi-circular arches are not subjected to any thrust.

(8) The mortar used for pointing joints should be only slightly richer than the jointing one, otherwise differences in shrinkage will cause the richer mortar to shrink and break away from the joint.

(9) Instead of 1 : 3 cement-sand mortar, 1 : 3 : 10-12 cement-lime-sand mortar *dashed* (not floated) makes a better job, and does not craze nor crack† in plastering exposed surfaces of walls.

Questions for Revision

(1) Discuss "Stone versus Brick" describing the merits and demerits of each.
(2) What are the functions of (a) Plinth, (b) Coping, (c) Jamb, (d) Parapet, (e) Footings, (f) Frog in a brick, (g) Queen closer, (h) String course?
(3) What is the object of preliminary dressing of stones at quarry site?
(4) Sketch good varieties of cornerstone, header and *khandkee.*
(5) Describe with sketches any two methods of securing two stones together against being washed away as in docks, top of weirs, etc.
(6) What is a Lewis? Sketch neatly any two forms of Lewis.
(7) What is the significance of break of joint in masonry?
(8) What is the general rough rule for proportioning the dimensions of a stone to be fixed into masonry?
(9) What are the general principles of securing a bond in masonry?
(10) What things will you observe while inspecting (a) stone work and (b) brick-work under construction?
(11) What is the difference between English bond and Flemish bond?
(12) What are the conditions of stability of a retaining wall?

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† Building Research Annual Report 1937 (H. M. Stationery Office, 1938, pp. 56-60).

COMPOSITE MASONRY : 5

Rubble-backed Ashlar: (Fig. 252). Rubble-backed ashlar is similar to the work described below, except that the backing in this case is made up of rubble. It possesses the same main drawback, viz., unequal settlement and the consequent separation of the facing from backing.

In this type of work, the face stones need not be squared on the sides for the full depth, nor need the back joints be vertical. But the bed joints must be dressed true and square for the full depth of the stone.

The facing must be bonded with through stones and headers, as explained above, but the sides of the tails of the stones may be left rough and tapering in plan. The headers from the rubble backing should preferably overlap the headers from the facing so as to create a perfect bond.

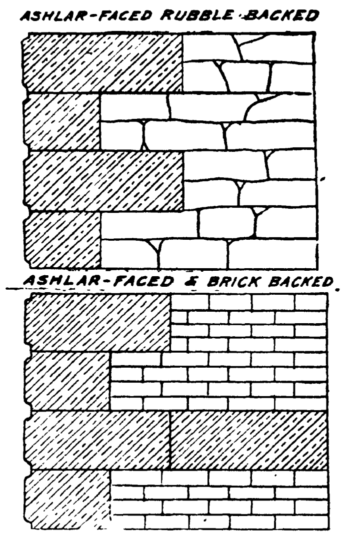
The minimum depth of the facing should be equal to the height of the course. If not properly supervised, the facing is often made of thin slabs having a depth equal to 10 to 15 cm. (4″ to 6″) with an equally thin slab of rubble backing on the opposite side, the interior being filled with small stones and chips and mortar. A wall constructed in this manner often bulges out, and is likely to collapse.

Brick-backed Ashlar: This type of masonry is occasionally used for obtaining better appearance offered by ashlar work at a lower cost. It consists of ashlar facing, backed with brick-work (Fig. 253.)

The portion with coarser and more numerous joints in brick-work is sure to settle down more than the fewer and thinner joints in the ashlar facing. This unequal settlement tends to separate the facing from the backing, which, if prevented by the introduction of bond stones, will probably lead to the bulging out of the facing.

In constructing brick-backed ashlar, the height of the facing stones is taken equal to a complete number of courses of the backing bricks, so that the facing and backing can be properly bonded together. The facing stones should be properly squared throughout, with the back joints vertical so as to leave no voids between the facing and the backing.

In addition to the bond stones extending through the entire width of the wall, a sufficient number of headers, penetrating into the body of the wall for a depth equal to two-thirds the wall thickness, should be used. This will ensure a reasonably perfect bond between the facing and backing.



Figs. 252, 253:
Top—Masonry with ashlar facing and coursed rubble backing.
Bottom — Masonry with ashlar facing and brick backing. Note the through stones laid for bond.

Concrete Masonry: Concrete masonry is the term used for the construction of walls with concrete blocks. Great progress has recently been made in the development of concrete block masonry. The advantages claimed over stone and and brick masonry are as follow:

(a) Saving of material and also of space due to the greater strength and uniform size of concrete blocks. Brick walls require to be thicker as the crushing strength of brick is less; stone walls, because their size is large and shape irregular, prevent a good bond being maintained unless the walls are at least 40 cm. (15 in.) thick. A concrete block wall, 20 cm. (8 in.) thick, is as strong as, if not stronger than 1½ brick wall, or 40 cm. (15 in.) of stone work.

(b) Saving in cost of labour, as the work is speeded up with a rectangular large size of block, and also in mortar, as the number of joints is smaller.

(c) Greater resistance to atmospheric influences than in the case of a brick wall which requires to be plastered on the outside.

(d) Less skilled labour is required, as the blocks are uniform in size and shape.

(e) With hollow concrete blocks, the walls afford good insulation against heat, cold, damp and sound.

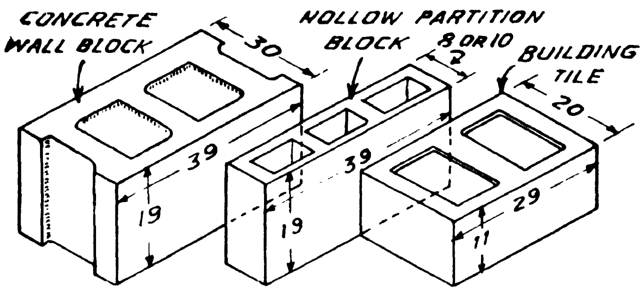
The blocks are moulded in machines either by the *cast* or *tamped* process, and consist of three sizes:

(i) Standard Size Blocks .... 40 cm. × 19 cm. × 20 cm.

(ii) Building Tiles .... 40 cm. × 10 cm. × 20 cm.

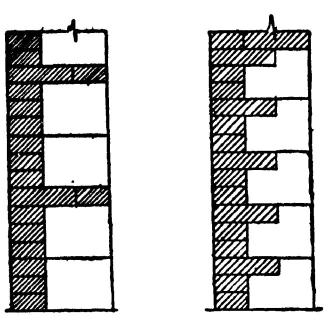
(iii) Partition Hollow Blocks 20 cm. × 19 cm. × 11 cm.

These types are shown in Figs. 254 to 256.



Figs. 254—256.

To facilitate construction, corner blocks, sills, lintels, and a few other specials are made of dimensions to suit the normal blocks used.



Figs. 257, 258: Wall with brick facing and hollow cement concrete block backing. Note the through layers of bricks inserted for bond.

The amount of air space in concrete blocks varies from 20 to 40 per cent of their volume. The modern tendency is to increase the air space to produce lighter units, easy to handle and lay. Thus, in the case of concrete building tiles, about 50 to 75 per cent of their gross volume may be formed by air space.

As the surface of the blocks or tiles is sufficiently rough, it provides a very good mechanical key for cement plaster, if desired. Any pleasing surface finish, either plain or in colours, may be given.

The following thicknesses are recommended:

TABLE NO. 14

No. of floors	Basement cm.	Ground Floor cm.	First Floor cm.	Second Floor cm.	Third Floor cm.
Ground	30	20	—	—	—
First	30	20	20	—	—
Second	30	30	20	20	—
Third	40	40	30	20	—

Figs. 257, 258 show composite masonry with brick facing. Note that for maintaining a bond between the two faces, through layers of bricks are constructed. The peculiar shape of the concrete blocks in Fig. 255 affords a better bond.

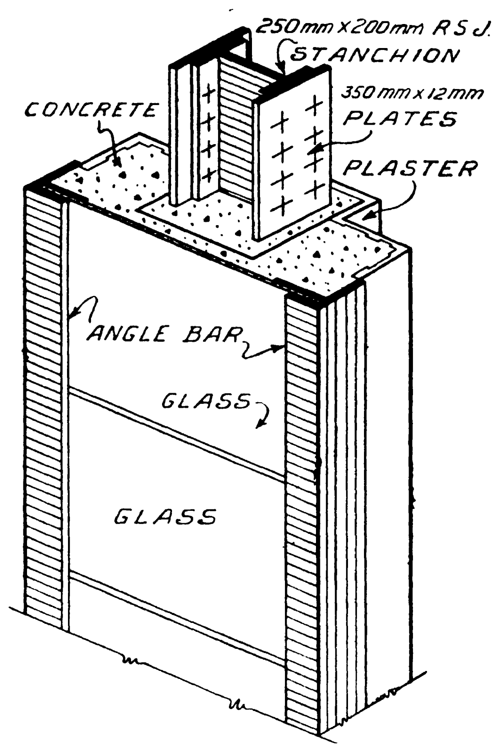


Fig. 259:
Concrete wall with glass slab for the outer skin. The glass is held in frames of stainless steel angles.

Glass Walls: Glass is coming more and more into prominence day by day as a structural material, and owing to the special and important characteristics it inherently possesses, viz. colourable transparency, ductility, and susceptibility to innumerable processes of refinement, and affinity to combine with reinforced concrete as an incorporate fabric, it has a great potential future before it as an important structural material.

Glass blocks, when used in the exposed walls, make windows unnecessary for giving light, and while performing this function, they also insulate the house against heat and noise, and give privacy and security. Further advantages are that the light is diffused, and may be given any desired tinge of colour, pleasing to the eye. As the surface is smooth, it does not catch dirt, and can be very easily cleaned. It does not allow condensation on the inside surface, in cold countries, which is a very great advantage in certain manufacturing industries, where high humidity has to be maintained within the building, e. g., the textile industry, where yarn of very fine count has to be handled.

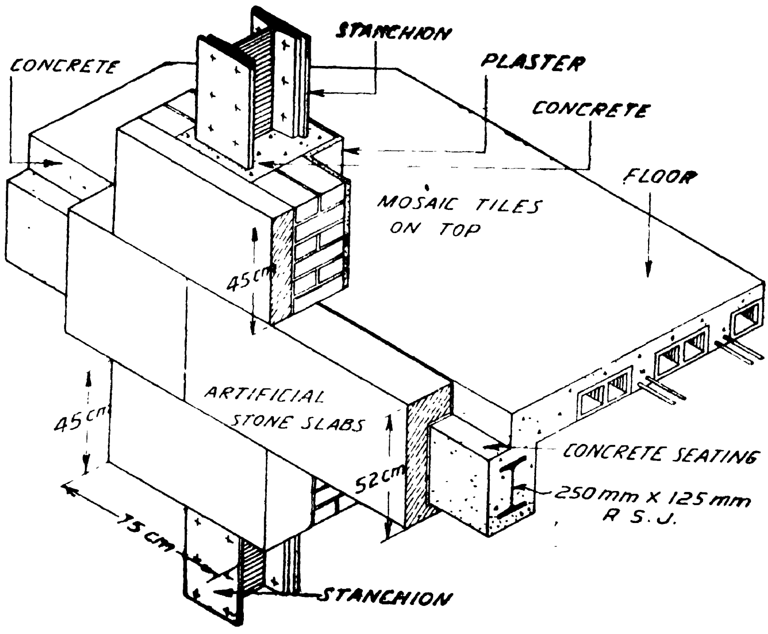


Fig. 260:
Isometric section of a panel wall with a steel frame. The latter is embedded in concrete. The panel wall has a skin of artificial stone slabs for the facing.

In plants where sanitary conditions must be strictly maintained, the non-porous and very smooth surface of glass blocks has recommended their use both for partitions and exterior walls, and last, but not least, the decorative possibilities of glass are endless.

Glass blocks used in the pavement of footpaths produce conditions of almost broad daylight in the basement rooms below the street level, which were, otherwise bound to be dark and dingy.

Fig. 259 shows the exterior wall of a building with glass slab facing and concrete backing. The slabs are held in angle frames of stainless steel. The walls serve as panels, the entire load of the building being carried by steel stanchions embedded in concrete.

Fig. 260 shows an isometric section of an exterior wall in which finely dressed stone slabs 5 cm. (2 in.) thick are used for the facing, and brick in cement mortar for the backing. These serve as panel walls. The entire load of the structure is borne by steel framework embedded into concrete for fire protection. The walls of the famous American sky-scrapers, such as the Empire State Building, Rockefeller Centre, etc., are built in this manner.

Questions for Revision

(1) What are the precautions to be taken for strength in brick-backed ashlar work?
(2) What are the advantages of hollow concrete block masonry?
(3) Show by means of a horizontal cross section how masonry with artificial stone slab facing, brick backing and mild steel framework embedded in concrete, is constructed.

SHORING, UNDERPINNING, SCAFFOLDING : 6

Shoring: Shoring consists of temporary struts supporting unsafe structures, the stability of which has been endangered due to the removal of adjacent buildings, unequal settlement of the foundation, or bad workmanship. The necessary support to an unstable structure is generally given by *raking shores* resting on the ground at one end, and abutting against the wall of the building at the other. Raking shores are shown in Fig. 261. A wall plate about 8 cm. × 22 cm. (3″ × 9″) is placed against the wall and secured to it by square needles which penetrate into the wall for a depth of about 10 cm. (4″) or so, and project outside the wall plate for an equal distance. These needles prevent the wall plate from sliding against the wall, and their projection serves as an abutment against which the inclined struts bear. The needles, against which the struts bear are placed at a point where the wall requires the greatest support. It is advantageous to nail

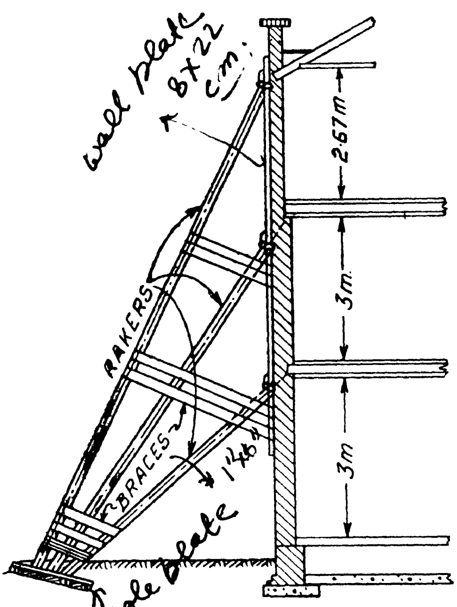


Fig. 261 :
Raking shore. Note that the upper ends of rakers are at the junction of each floor where supports are needed most.

a wooden cleat immediately above the needle, so as to increase the resistance of the same. Various raking struts are interconnected by braces 2·5 cm. (1″) thick and 15 cm. (6″) wide nailed on the sides of the struts. The position of the braces is immediately below the needles. Similarly at the base, the struts are tied together by hoop iron. The braces and hoop-iron tied at the base help in keeping the struts in their position. The support at the base of the struts consists of a timber sole piece firmly bedded into solid ground. The struts are secured to the sole piece by dog spikes.

The smaller the angle of the struts with the horizontal, the greater will be the effective resistance of the struts. An angle of 45° would perhaps be quite effective, but this would require a great deal of room on the side and very long struts. Therefore, struts are used in practice at a much greater inclination to the horizontal.

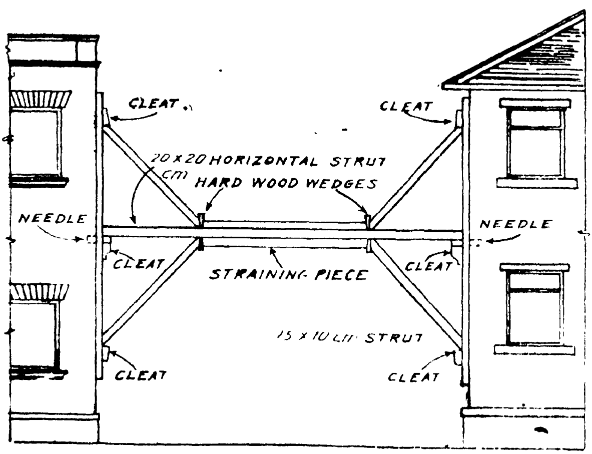


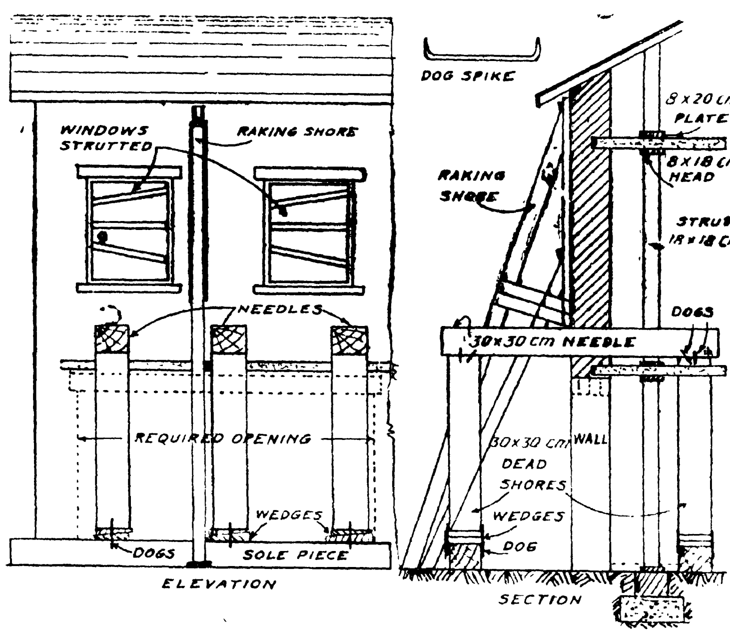
Fig. 262 :
Flying shores.

It occasionally happens that in a series of buildings standing side by side, one of the intermediate buildings has to be pulled down and rebuilt. The removal of such a building considerably impairs the stability of the end walls of those on either side, and they require a temporary support until the intermediate building is reconstructed. Such walls can be supported by *flying shores* as shown in Fig. 262 from which it is clear that

the shores temporarily take up the position of the dismantled building.

Underpinning: When by reason of failure, or for the purposes of alteration, it is required to re-build the lower part of a building, without damaging or dismantling the upper one, underpinning has to be resorted to. It may be necessary either for rebuilding or deepening of the foundations or for rebuilding or removing of the wall above the ground, as in the case of fitting new doors, windows or shop-fronts.

Where foundations are to be underpinned the excavations are carried down to the level of the proposed new work and sections of brickwork, about four or five feet in length at a time are cut out and replaced or built down to the proposed new level. If this is carefully done, the building stands in no danger of damage. When the new work in one section is put in and is

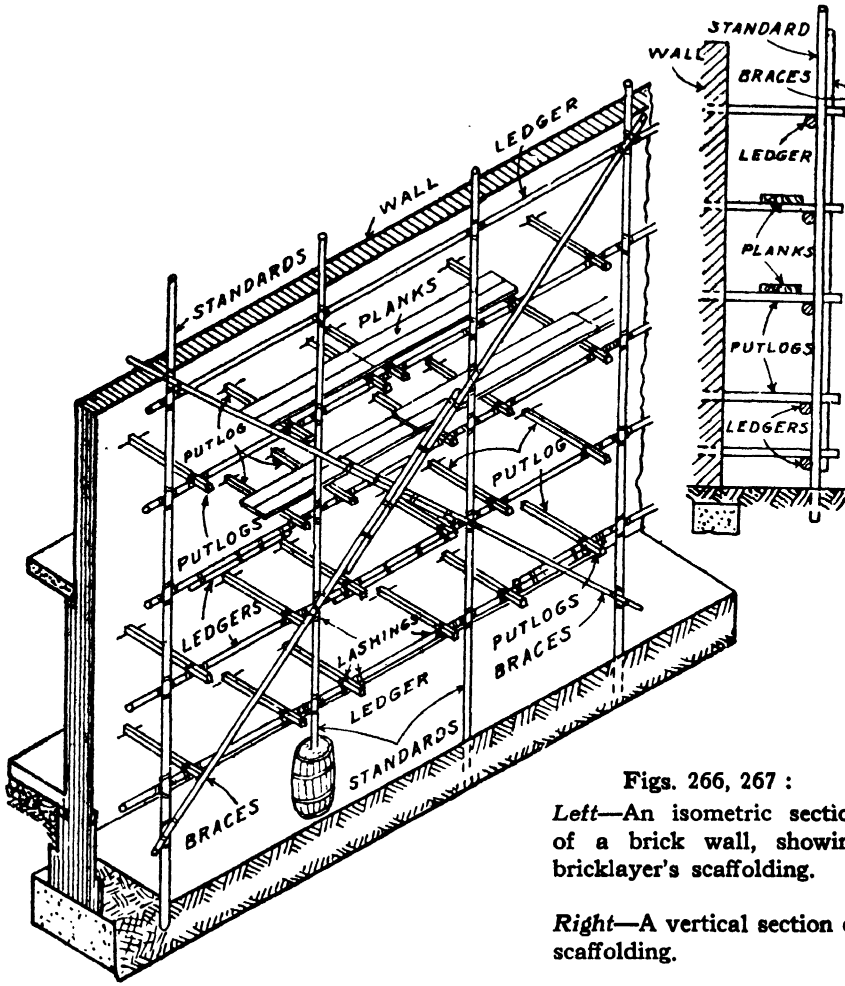


Figs. 263—265 :
"Dead" shores.

set firm, the adjoining section of four or five feet in length is similarly dealt with. This process is continued until the

foundation under the entire length of the wall is renewed. The earth filling in each section is done as soon as the section in question is completed.

When walls above ground are to be removed, or re-built, the method of supporting the structure, although requiring ex-



Figs. 266, 267 :
Left—**An isometric section of a brick wall, showing bricklayer's scaffolding.**

Right—**A vertical section of scaffolding.**

treme care on the part of the workmen, is quite simple in principle. It consists in merely breaking one or more small holes through the wall and inserting stout needles or beams sufficiently strong to carry the weight of the wall above and projecting at right angles on each side of the wall to admit a stout prop being

placed under each end. The props are made to rest on a sole piece, firmly bedded in the ground, and have at their bases a pair of folding wedges for tightening up the beam against the wall which it has to support.

In order to relieve the beams of the weight of the floors and roof, the latter are independently supported by props called *dead shores* as shown in Figs. 263, 264. The raking shores to the wall above the portion to be dismantled are used for additional safety. Fig. 265 illustrates a dog spike used for strengthening timber joints.

Scaffolding: A scaffold, as used in building operations, is a temporary structure supporting platforms by means of which the workmen and their materials are brought within reach of the work.

The scaffolds used by masons are slightly different from those used by bricklayers, but the construction is essentially similar. This temporary structure consists of vertical standards, spaced at about 8′ centre to centre, and connected to each other by horizontal ledgers, spaced at a vertical distance of 1·5 m. (4′ to 5′). Cross timbers known as *putlogs,* spaced at 1.25 m. (4′) centre to centre, are supported on the ledgers on one side, and in holes in the wall on the other. The putlogs, in their turn, support the timber planking forming the working platform. The width of the platform is usually about 1·5 m. (5′).

In the case of masons' scaffolds, two rows of standards are used—one next to the wall, and the other at a distance of 1·5 m. (5′) and the putlogs are supported at both ends on ledgers. This is more convenient as it is not possible to leave holes in stonework at regular intervals. Thus, the mason's scaffold is completely independent of the wall.

The standards, the ledgers, and the putlogs are fastened to one another by the lashing of rope, and nails are rarely, if ever, used.

As the work proceeds, the platform is raised higher and higher and, if necessary, the standards are lengthened by adding extra pieces. For longitudinal stability of the scaffolding, diagonal braces are used. Bricklayer's scaffolds are shown in Figs. 266, 267.

Rope lashings for scaffolding require much skill on the part of the scaffolder. Besides making demands on his time and skill,

rope is subject to many disadvantages such as slipping, slackening, fraying, cutting, etc. During recent years, these have been superseded on large works by more scientific devices such as *scaffixer* lashings, consisting of a combination of steel chains and ingenious devices of fastening, which effect a considerable saving of time, while affording greater security.

Tubular Scaffolding: A greatly improved system of patented scaffolding consists of about 4 to 6 cm. (1½″ to 2½″) diameter weldless steel tubes of 6 W. G. thickness connected by patent couplers. Such scaffolds can be erected in position and dismantled with great rapidity and ease. The tubes are fixed by the turn of a simple set screw, which rigidly holds them together. Another advantage is that it is not necessary to leave holes in the wall for resting part of the scaffolding as required for the putlogs in the ordinary scaffolds. Just a little ledge in one of the joints is sufficient.

Suspended Scaffolds: Heavy, suspended scaffolding, which can be mechanically raised or lowered, is suitable where steel frame construction is adopted. It is suspended by wire ropes from cantilevers above, and is designed to carry all the usual loads.

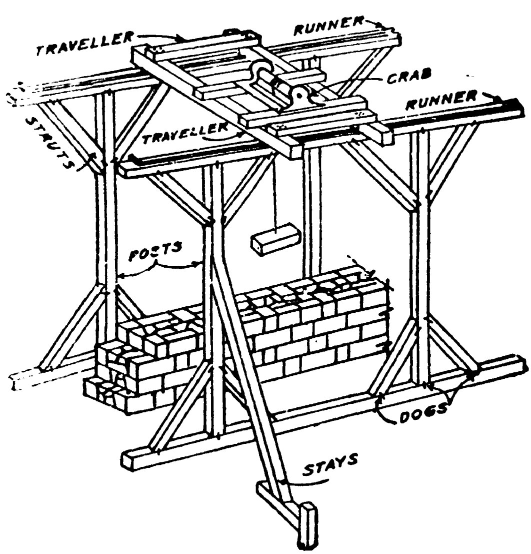


Fig. 268 :
Gantry with a traveller.

Gantries: The scaffolding described above can be used for works where the materials used in the work can be easily handled by the masons. But where the blocks of stone used in the work are too large, and require a lifting tackle, the scaffolding as described above is unsuitable, and a gantry carrying a traveller and a crab, is necessary (Fig. 268).

The staging or gantry is formed of squared timbers in the same manner as the mason's scaffold, but with only one row of standards on either side of the wall. The standards carry, at their top, longitudinal timbers or runners on which a line of rails is fixed. The spacing of the standards is between 3 m. and 6 m. (10′ and 20′) depending on the size and the weight to be supported. Corbel or *cap* pieces are sometimes placed under the runners to give the latter a better bearing on the heads of the standards.

A travelling platform, carrying a lifting tackle, moves on the line of the rails parallel to the length of the gantry. A line of rails is also provided on the platform which enables the lifting tackle to move in a direction perpendicular to the length of the gantry. Thus, any point within the area occupied by the gantry can be reached by the tackle.

In some cases, the tramway leading from the quarry is laid between the outer row of standards and the wall, to admit of the stones being lifted directly from the truck on to the work. In such a case, the distance between the wall and the outer row of standards is required to be greater, say about 5 m. (15′).

To prevent lateral movement of the gantry, struts from the ground are usually fixed to each standard as shown in Fig. 268. The struts should rest at the bottom on foot-blocks firmly bedded into the ground, and a short pile should be driven on the outside of the foot-block so as to prevent its movement outside. The joints are further strengthened by hammering dogs in timbers on both sides of the joints.

Questions for Revision

(1) Under what circumstances are raking shores useful? What are the essential parts?

(2) What are flying shores and why are they so called?

(3) What is underpinning? When underpinning is done at or below foundation level, why is the work done in small alternate sections, leaving gaps between to be done later?

(4) What is the difference between a stone mason's and a brick mason's scaffolding? Sketch a brick mason's scaffolding, naming the different parts.

(5) What are the advantages of steel tubular scaffolding?

(6) What is a gantry, and under what circumstances is it used in preference to a scaffolding?

PARTITION WALLS : 7

THE function of a partition wall is to divide a large room into two smaller ones, and to afford privacy. It is only in rare cases that a partition wall has to bear a structural load in addition to its own. When it serves also as a bearing wall, it is designed either on the principle of a truss, or as an R. C. C. beam of considerable depth.

The principal advantage of a partition is that it saves space, and with modern materials it can be made very light so that it can be erected on the upper floor without a supporting wall or even a beam below it.

The requirements of an ideal partition are that it should be thin, light, rigid, affording privacy both in respect of sound and sight, simple and easy of construction, fire-resisting and cheap. Amongst these, privacy and fire-resistance are of great importance.

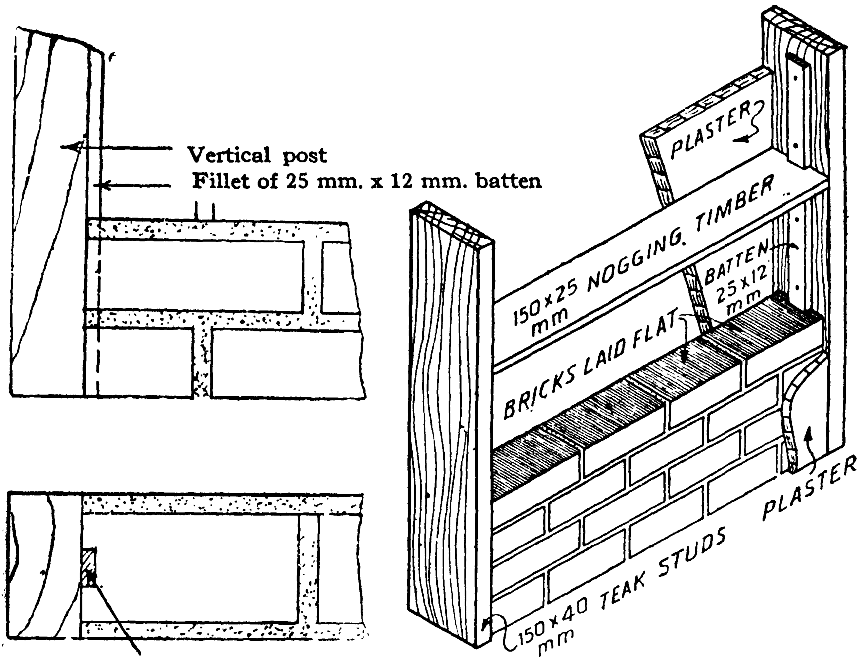
Partition walls may be classified into:

(1) Brick partition—plain, brick-nogging, or reinforced brick-work.
(2) Lath—wooden or steel—with plaster, on both sides.
(3) Hollow partitions of concrete or clay tiles.
(4) Fibre-board partitions.
(5) Wooden—trussed, folding, or sliding.
(6) Glass partitions.

(1) **Brick Partitions:** If these are of plain brick-work in mortar, they require to be at least one brick thick, to be self-supporting and reasonably sound-deadening. Thus they occupy much space and are expensive, since they have to be further plastered on both sides.

For brick-nogging, a wooden frame work consisting of vertical studs 0·75 m. to 1·5 m. (2 to 5 ft.) apart and horizontal timbers between, spaced at 0·75 m. to 1 m. (2′ to 3′), should be made. The width of the timbers should preferably be equal to

the thickness of the partitions, including plaster on both the sides. Thus, if the bricks are 6 cm. (2½″) thick and are placed on edge, the timbers should not be less than 10 cm. (4″) wide; and if they are laid flat in stretching bond, the timbers should be 15 cm. (6″) wide. Mortar does not stick well to a wooden surface; besides, it is liable to shrink. In consequence of this,



Figs. 269—271 :
Left—Section and plan of a brick-nogged partition wall, showing the fillet of a batten nailed to a vertical post to hold the panel of brick partition firmly.

Right—An isometric view of the same.

the panels of brick-work between timbers are likely to become loose and shaky, particularly if there are doors in the partition which are liable to cause vibrations in it when opened or closed with a bang. To check this, fillets of teak-wood battens 3 cm. × 1·5 cm. (1″ × ½″) should be nailed to the vertical timbers on the inside of panels as shown in Figs. 269 to 271, and a suitable groove cut in the end of the bricks laid against it.

Reinforced brick partitions are similar to brick-nogging except that instead of the horizontal timbers, either straps of hoop iron 24 mm. to 36 mm. (1″ to 1½″) wide and 2 mm. (1/16″) thick, or patent expanded metal bands called "exmet" are laid horizontally in every fourth or fifth course between the vertical timbers, and cement mortar is used instead of lime mortar in that layer. About 25 mm. (1″) of the hoop iron straps or exmet is bent at ends at right angles and nailed to the vertical timbers at sides. Instead of hoop iron, two 6 mm. (¼″) mild steel rods spaced at 8 cm. (3″) apart may be laid with their ends inserted about 25 mm. (1″) into holes drilled into side timbers or embedded in the masonry of the side walls.

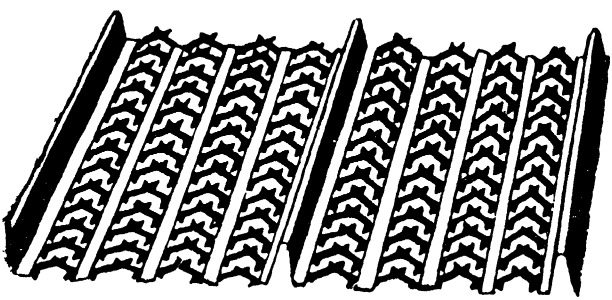


Fig. 272 :
Hy-rib steel lathing.

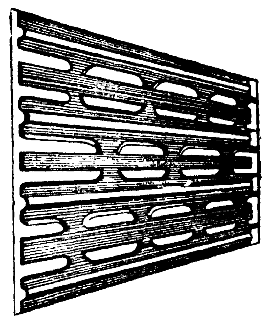


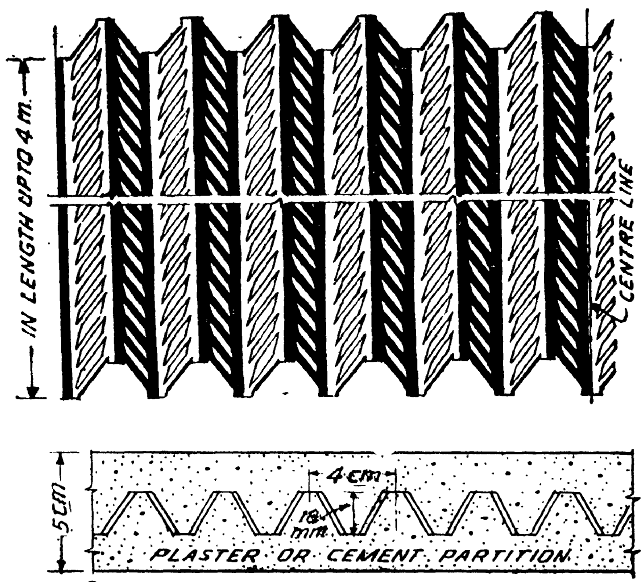
Fig. 273 :
Jhilmil lathing.

(2) **Lath and Plaster Partitions:** Laths may be of wood or metal. Wooden laths are thin strips of well-seasoned wood, about 25 mm. (1 inch) broad, 1 to 1·5 m. (3 to 5 ft.) long, depending on the spacing of vertical timbers or studs, and of thickness according to the size used, viz., (i) Single, 2 to 3 mm. (⅛″ to 1/16″), (ii) Lath and a half, 6 mm. (¼″), and (iii) Double 8 to 12 mm. (⅜″ to ½″) thick. They are fixed to the wooden studs in parallel lines with a space of 8 to 12 mm. (⅜″ to ½″) between, by means of galvanized iron special lath nails 18 to 32 mm. (¾″ to 1¼″) long with staggered butt joints. However, on account of the climatic variations and liability of attack by white ants, wooden laths are not much used in this country except for temporary structures, where split bamboos, with the glazed bark on inside are laid not in horizontal

lines, but diagonally crossed like a trellis, nailed at ends and wired at junctions and plastered.

Metal laths are of several kinds. Most of them are the subjects of patents. Some of these require a framework either of steel or wood for rigidity to which these, like expanded metal sheets, wire-netting, B. R. C. fabric, etc., are nailed or tied down by wires. Others possess stiffening ribs to make them sufficiently rigid. Among the latter may be mentioned *Hy-rib, Jhilmil, Trussit, Self-centering, Truscon, Herringbone, Rigid,* and so on. *Hy-rib* and *Jhilmil* are shown in Figs. 272 and 273.

Metal lath has the advantage that in addition to serving as a plaster base, it reinforces the plaster, precludes, or at least minimises, the possibility of cracking, and makes the partition fire-resisting.



Figs. 274, 275 :
Elevation of "Tussit" steel lathing and horizontal cross section of partition of Trussit plastered on both sides.

Trussit illustrated in Figs. 274 and 275, is a metal lath of the corrugated expanded type specially designed for partitions. The corrugations are connected by a *Herringbone* pattern which provides a good key for the cement plaster. The surface has to

be temporarily supported while being plastered. The finished partition is 4 cm. to 6 cm. ($1\frac{1}{2}''$ to $2\frac{1}{2}''$) thick and is fire-resisting. The sheets can be fixed to timber at end by means of U-shaped wire staples and to steel by means of clips, or simply by wiring. The sheets are 50 cm. (19 in.) wide and 4 m. (12 ft.) long.

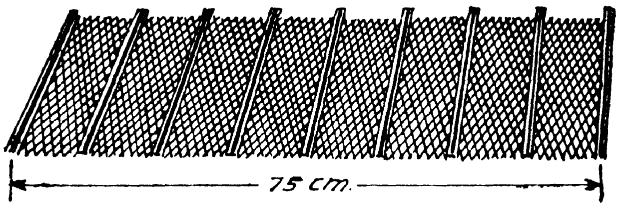


Fig. 276 :
"Self-centering" expanded metal with ribs connected by diamond mesh. It is used both for partitions and floor-slabs.

Self-centering is a ribbed type of expanded metal lath of steel. The ribs are connected by diamond mesh expanded metal as shown in Fig. 276. The sheets are used both for partitions and R. C. C. flooring for which no centering is required.

(3) **Hollow Partitions:** In a variety of these, a framework of timber is made, and wall boards are nailed or screwed on its both sides. The hollow space between them is filled with lean cement concrete or coke breeze concrete. If the wall boards are fire-resisting and the filler material is fibrous or porous like coke breeze, not only a fire-resisting but also a reasonably sound-deadening partition is formed. A number of such boards are now available in the market. Amongst them may be mentioned *Masonite Pressed Wood, Asbestos Wood, Essex Boards, Celotex, Armoured Plywood, Fibrelic, Venesta Plywood,* etc.

Hollow blocks of concrete suitable for partitions have been already discussed and shown in Fig. 255, p. 125. Hollow terra-cotta blocks, which require to be filled with cement concrete, also form good partitions. Other patented materials are *Phorpres* hollow partition blocks (Fig. 277) made from British clay. *Moler* blocks made also from earth of marine origin and *Cranham* blocks made from porous terra cotta, are products for which the manufacturers claim excellent fire and sound resisting properties in addition to extreme lightness and strength. They have joggles cast on their surface which make them interlock into each other.

The burnt clay tiles, shown in the partition in Fig. 278, have such joggles. The sketch shows eel glass quilt packed between the tiles on either side to form a sound-proof and fire-proof partition, the grass being chemically of silicate origin.

(4) **Fibre Board Partitions:** Fibre board is the general name of a variety of thin patent slabs on the market. Some of them such as *Indianite,* are made from seaweed. Others like *Feathercrete* are made from rice husk. The binding material is Portland cement. Pumice slabs and gypsum partition bricks are similar proprietary materials. Rectangular slabs of varying sizes and thicknesses of 7·5 cm. to 10 cm. (3″ to 4″) are moulded and pressed in a machine. The slabs are laid on edge in cement and plastered. Since fibrous or cellular material goes into their composition, they are extremely light, and effectually damp sound waves.

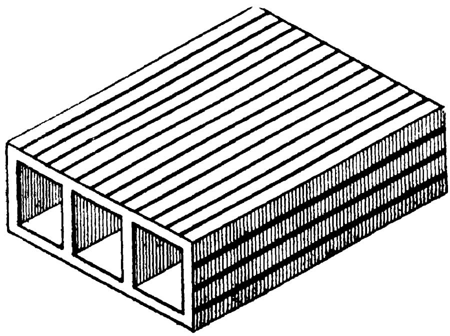


Fig. 277 :
"Phorpres" hollow partition block. Steel reinforced block 22 cm. x 16 cm. x 5 cm. (9 in. x 6½ in. x 2 in.)

(5) **Timber Partitions:** On account of their high cost and susceptibility to destruction by fire and white ants, these are not commonly used. Besides, in the tropics even though the timber may be well seasoned, it is liable to shrink in summer and swell in the rainy season and so they have never been popular in this country.

They may be divided into two classes, viz., common and trussed. The weight of the common partition falls on the floor, while that of the trussed is borne by the side walls on which the trussed partition rests.

Sometimes folding and sliding wooden partitions are used. The framing must be of a minimum thickness of 4 cm. (1½″). The partition is either top hung, or its weight is carried on the floor. The former should be done only where structural or other conditions render it necessary. In either case the folding or sliding is operated by a gear. All the leaves are usually hinged to-

gether, the one at the end being securely fastened to the wall. On no account should cast iron fittings be employed as they are liable to break without notice and cause accidents. The runner sections should be of a non-rusting type, fitted with ball or other bearings. The floor rail should be flush, and of a design easily kept free from dirt. Centrally swivelled folding partitions are preferable as they are perfectly balanced when folded.

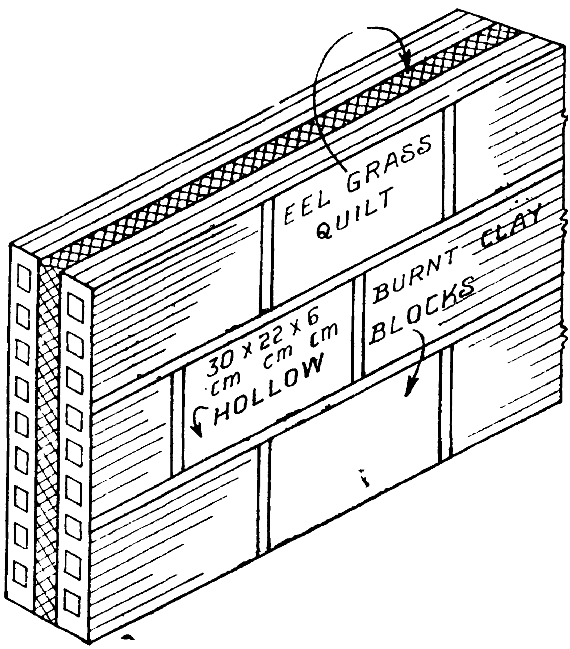


Fig. 278 :
A partition of burnt clay hollow tiles with a quilt of eel grass packed between them. This makes a light, sound, fire-proof and sound-proof partition.

(6) **Glass Partitions:** For these a wooden framework is made, and sheets of glass are fixed in it in the form of panels. Glass partitions are very light, take the least space, are very good insulators of sound if the panes are thick enough, and if sand-blasted or frosted glass is used, they afford a reasonable degree of privacy. One special advantage, glass partitions possess over all others, is that, they transmit diffused light. Any decorative effect can be given to glass partitions. Further, glass, being one of the

cleanest materials, saves labour in cleaning. The only objection is that it is breakable. However, scientific research has recently made such advances that not only is that objection removed, but

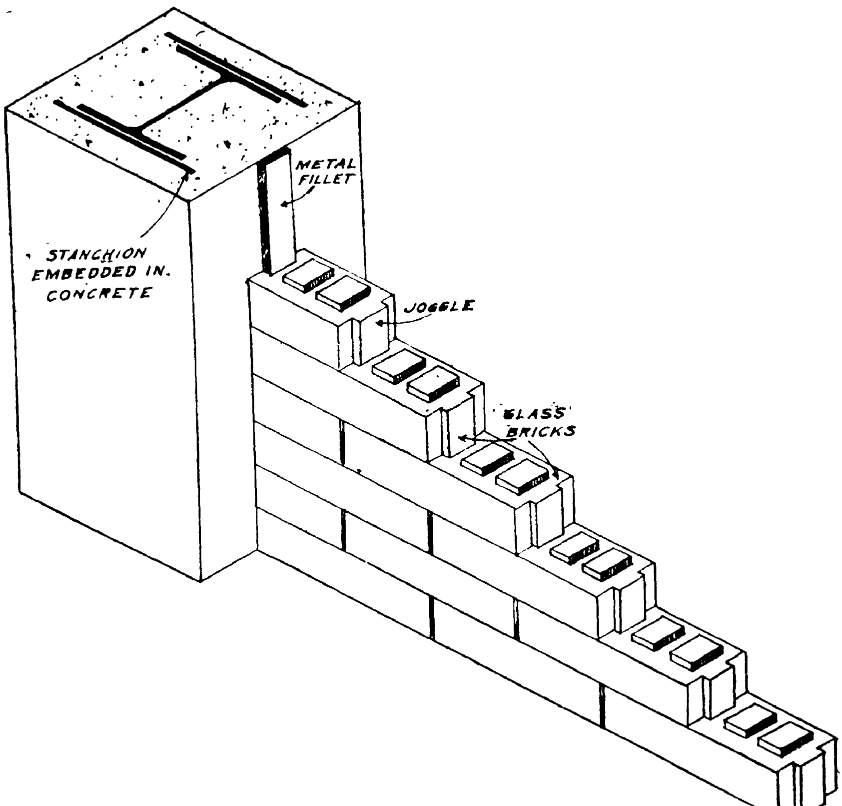


Fig. 279 :
Partition of solid glass-bricks.

certain other advantages added. Thus wired sheets of glass reinforced with steel wire netting are very hard and practically unbreakable, and if they do break at all, splinters are not produced. Then there is the safety three-ply glass, consisting of two or three pieces of glass between which, is introduced a sheet of transparent celluloid, or similar material. The third is *Armour Plate Glass* recently perfected which is not composite in character, but possesses shock-resisting properties to a remarkable extent.

Glass bricks and slabs have recently been introduced and these do not require a wooden or steel framework to form a wall or partition. The bricks have joggles cast on them both on the top and ends which interlock with each other and form a rigid partition. Fig. 279 shows one such partition which is joined to the main wall by means of metal fillets with corresponding grooves in the bricks laid against them. The fillets are screwed to the main wall. These however being heavy, require a wall or a supporting beam at bottom.

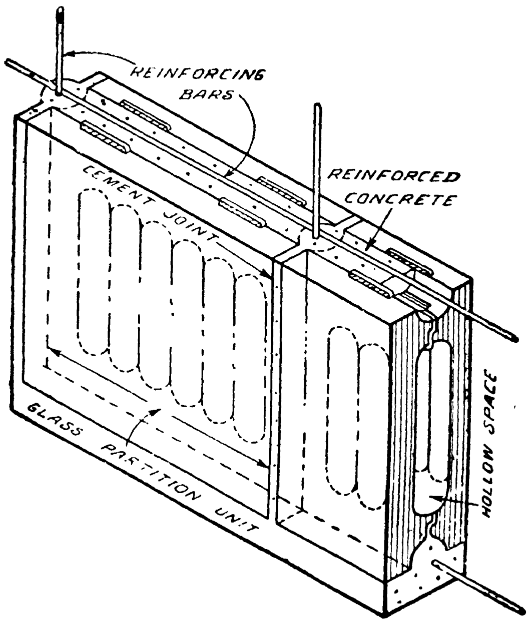


Fig. 280:
Glass slab partition reinforced with steel rods.

Another form of partition of glass which is, in fact, a reinforced glass partition, is shown in Fig. 280. It is formed of separate glass units with hollow spaces between them, erected on either side, and joined together with cement concrete in which horizontal and vertical steel rods are embedded.

DOORS AND WINDOWS : 8

Doors: Doors consist of a frame, and either one or two shutters hung to the frame by means of hinges. Doors with two leaves are known as *hung folding* or *double leafed, and* those with one leaf are known as *single-leafed.*

In India, it is customary to provide even narrow doors in partition walls with two-leafed shutters. In England and on the Continent, even main doors are single-leafed. Both systems have their advantages and disadvantages. The best course is to adopt single-leafed doors in partitions and double-leafed in walls. With single-leafed shutters there is a saving in the hinges and other fittings, as also in labour. Further, they occupy the least space if they are placed in a corner and allowed to open against a wall. If partition walls are more than 15 cm. (6″) thick, it is advisable to use parliamentary (see Fig. 341) hinges by means of which, the shutter can be made to open flat against and parallel to the wall, so that it causes the least obstruction.

Sizes of Doors: Sizes of doors can be varied to suit the requirements, and no general rules specifying them can be laid down.

The overall dimensions of a door are usually determined by making the width equal to the height minus 120 cm. (4 feet.) The minimum height of a door is 180 cm. (6′) without a fanlight, and 2·3 m. (7′ 6″) with a fanlight, whereas the maximum is usually not more than 2·3 m. (7′ 6″) without a fanlight, and 2·75 m. (9′ 0″) with a fanlight, in ordinary buildings.

The frame of a door is made of timber scantling usually 8 cm. × 10 cm. (3″×4″) for doors of normal sizes, the section of the scantling being suitably increased for larger ones. In the case of doors in partition walls, it is advisable to make the thickness of the frame scantling equal to the thickness of the partition wall including plaster, particularly if the partition is of brick nogging. If it is not done, the projecting corners of the plaster are likely to be knocked off every now and then.

The horizontal top member of the door frame is called the *head* which is mortised to take the tenon formed at the ends of the vertical *posts* of the frame. A draw pin is used to hold the shoulders of the tenon tightly home. The ends of the heads are sometimes allowed to project so as to form *horns* which are built into the wall. The bottom horizontal member of a door frame is known as a sill. The joint between the sill and the posts is similar to that between the head and the posts, and the sill is also sometimes allowed to project so as to form horns which can be built into masonry.

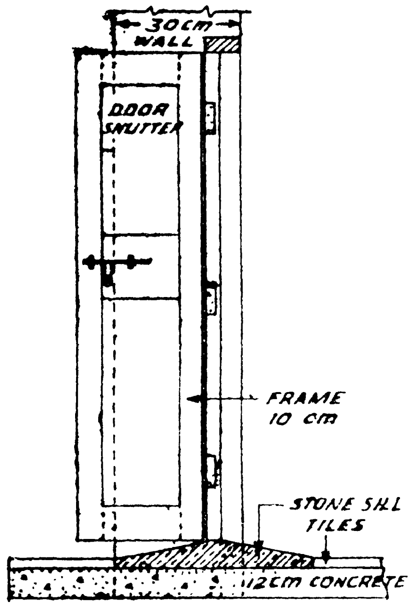
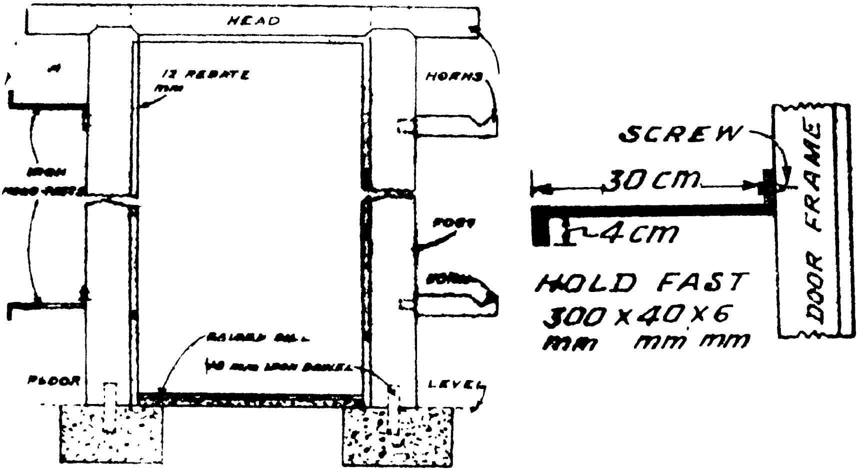


Fig. 281:
A door with raised sill.

The modern trend is to omit the wooden sill of a door frame as it causes an obstruction to the movement of the occupants, and does not permit of easy cleaning and washing of floors. Omitting the bottom sill causes some difficulty in opening and closing the door, if a carpet or coir matting is spread on the floor across the door opening. If, to avoid this difficulty, the door shutters are raised above the floor by 3 cm. (1″) or so, an unsightly gap remains through which, not only sound may be communicated to the outside, but rain-water if the door be exposed, may come in; further, the gap may give passage to vermin, small rats, and reptiles. To remedy this, the sill portion of the door, equal in width to the timber of the door frame, should be raised by 2 to 3 cm. (¾ to 1 in.) and the jamb and reveal portion of the sill sloped down on either side from it to meet the floor level as shown in the vertical section through the centre of the door in Fig. 281. The bottom of the door shutter will thus remain 2 to 3 cm. (¾ to 1 in.) above the floor level, and will not interfere with a carpet and will also facilitate cleaning and washing.

In order that the frame should not become loose or shaky due to the frequent opening and closing of the door, wooden pegs



Figs. 282, 283 :
How a door frame is fixed into a wall and floor, is shown in the figure.

called horns, about 15 cm. (6″) long, are sometimes driven at right angles into the sides of the frame and embedded into the masonry. But this is not a very satisfactory method of fixing a frame. Instead, an iron hold-fast, 3 mm. to 6 mm. (1/8 to 1/4 in.) thick and 25 mm. to 40 mm. (1 to 1½ in.) wide, bent as shown in Fig. 283 with one of its ends nailed or screwed to the frame and the other built into the masonry, serves the purpose satisfactorily.

A 12 mm. (½ in.) deep rebate, equal in width to the thickness of the shutter, is provided on the sides of the frame to receive the shutter.

Shutters are of various kinds of which the following are important:

(1) **Ledged Door**: (Fig. 284) This is a simple and common type of door, consisting of narrow battens 15 cm. (6″) wide by 18 mm. to 32 mm. (¾″ to 1¼″) thick, tongued and grooved, and beaded or V-jointed, secured by three horizontal ledges. It is hung with cross garner or "T" hinges (Figs. 284, 285) fixed on the ledges, or by narrow butt hinges fixed on the edge of thicker boarding. This is not a strong and satisfactory door and is used for out-buildings.

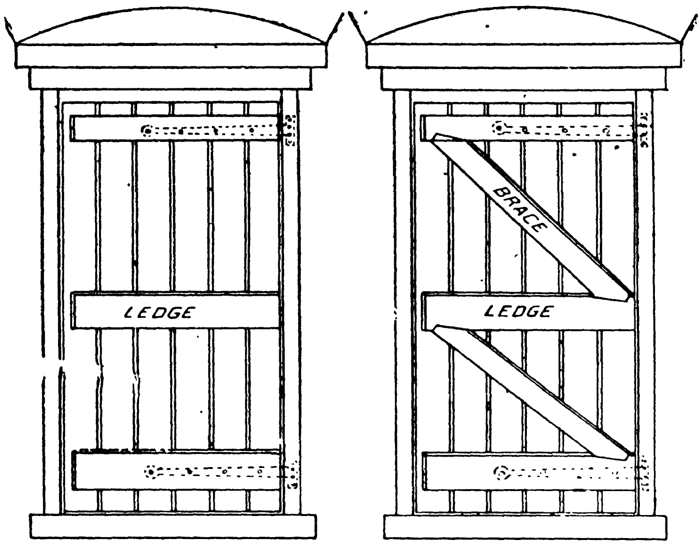


Fig. 284 : Ledged door. Fig. 285 : Ledged and braced.

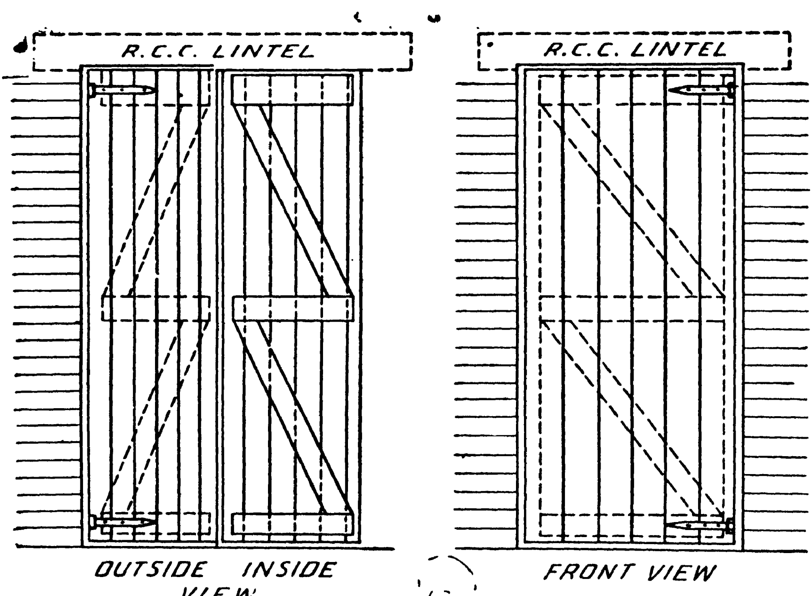


Fig. 286. Fig. 287.

Figs. 284—287 : Doors framed, ledged and braced.

Other Miscellaneous Types of Doors

Collapsible Doors: These consist of vertical double pieces of mild steel channels 16 mm. to 18 mm. (5/8 in. to 3/4 in.) wide, joined together with the hollows of the channels on the inside, leaving a vertical gap between them of 12 mm. to 18 mm.

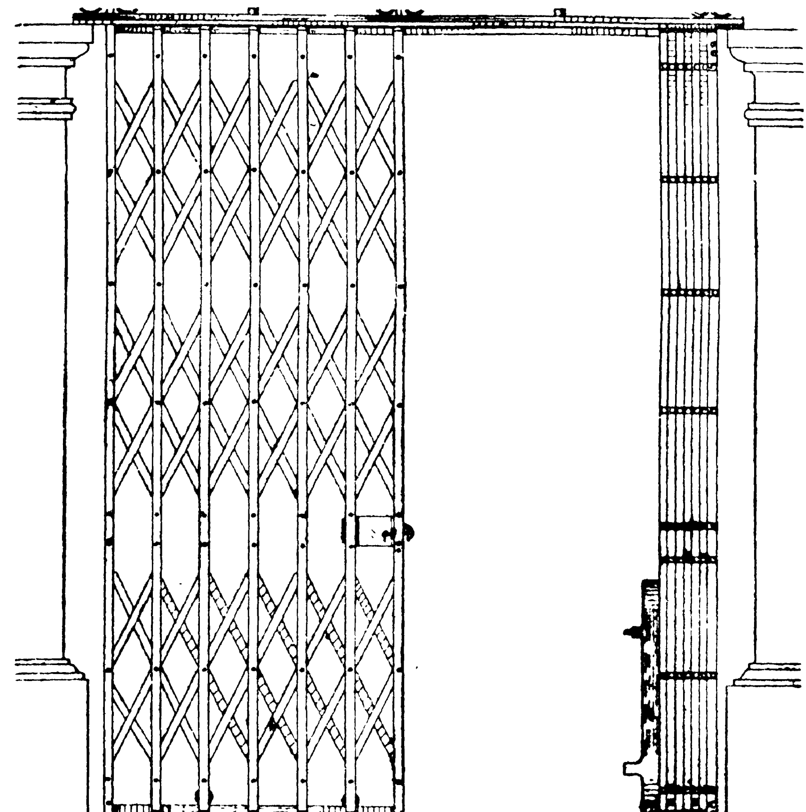
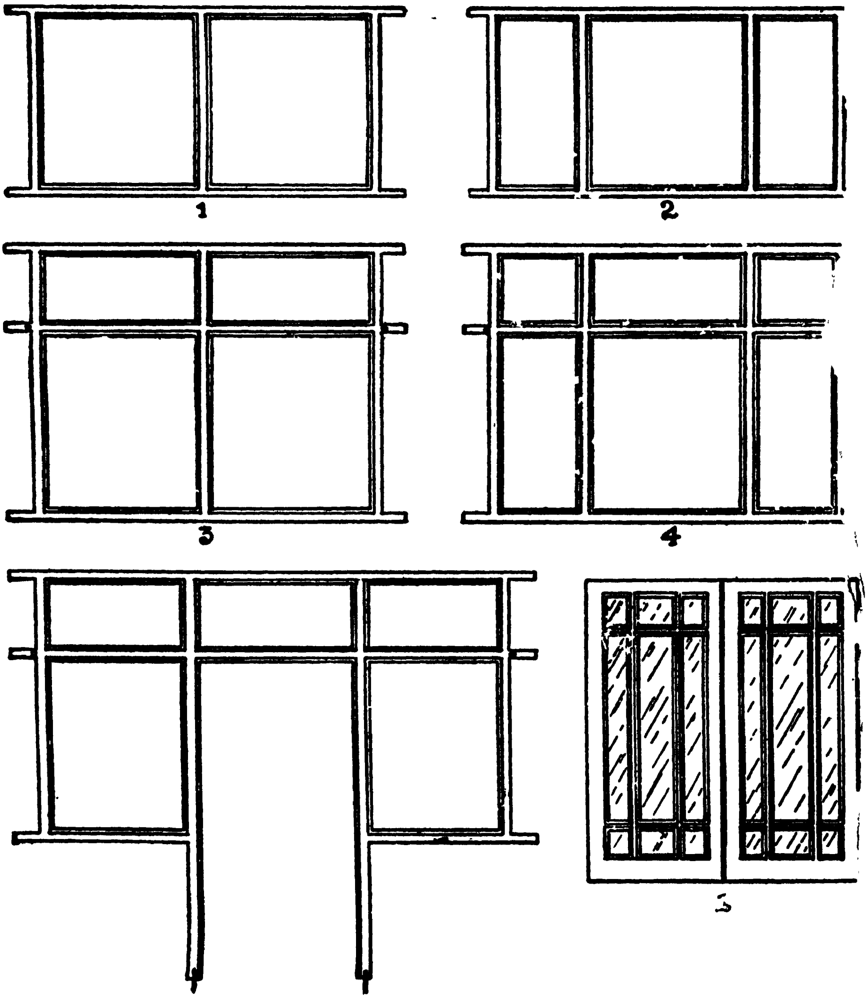


Fig. 310 :
Collapsible steel gate.

(1/2 to 3/4 inch.) Rollers are mounted both at their bottom and top. The pieces are spaced at 10 cm. to 12 cm. (4½″ to 5″) c. to c., and are joined to one another by means of hoop-iron cross pieces 16 mm. to 10 mm. (5/8″ to 3/8″) wide and 5 mm. (3/16″) thick which allow the door to open or fold. At the sill

and top, are fixed in walls, horizontal pieces 10 mm. ($\frac{3}{8}''$) thick on edge, between which the rollers work when the door is opened or closed. (See Fig. 310).



Figs. 311—316 :
Different forms of windows. The last is a pair of glazed shutters. Frame No. 5 is suitable for an entrance to a balcony or gallery.

Wire Gauze Doors: These doors are commonly used for refreshment rooms, kitchens, larder cupboards, meat safes, etc., to keep out flies. The shutters which are hung to the frame by

to get away. The edge of the glass projects 4 cm. ($1\frac{1}{2}''$) beyond the lower edge of the bottom rail, and is held by copper clips.

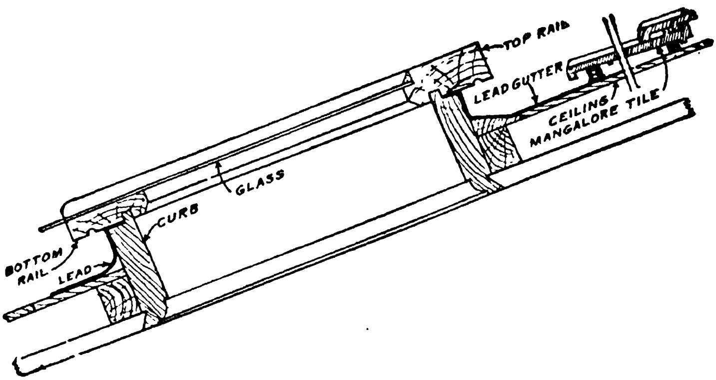
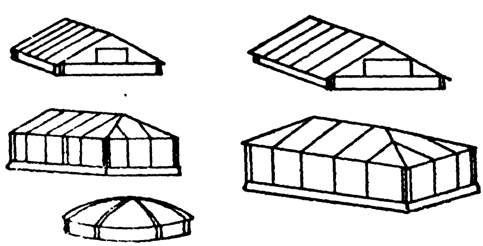


Fig. 326:
Skylight.

In roof coverings of Mangalore tiles, the purpose of a skylight can very well be served by substituting glass tiles of the Mangalore pattern in the required portion. This is much simpler and cheaper than providing the elaborate arrangement previously described.

Lanterns: Lanterns or lantern lights, as they are sometimes called, are windows fixed in a flat roof for lighting passages or inner apartments to which light from windows in the exterior walls cannot reach. Figs. 327 to 331 show isometric views of a few different types of lanterns. For details of construction, refer to the chapter on Roofing.



Figs. 327—331:
Five different varieties of lantern lights.

Fixtures and Fastenings for Doors and Windows:— (1) *Hinges:* Many types of hinges are used on doors and windows, but only those which are common are described below:

Figs. 332 to 334

335 to 338

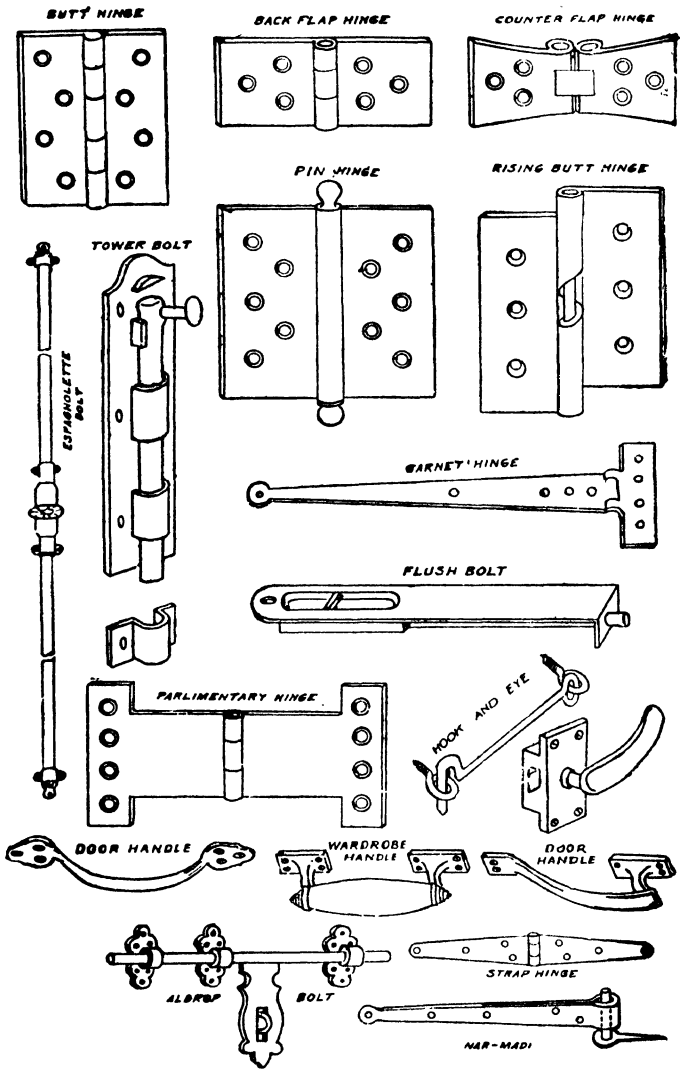
339

340

341 to 343

344 to 346

347 to 349



(a) *Strap Hinges:* These are illustrated in Fig. 348. The long arms of the hinge are fixed to folding shutters, whereas the

other is fixed to the rebate in the frame. This type of hinge is mainly used on planked shutters such as those of ledged or ledged and braced shutters, etc. *A garnet hinge* (Fig. 339) serves the same purpose. (Compare *Nar-madi,* Fig. 349).

(b) *Butt Hinges:* (Fig. 332.) These are most commonly used on doors and windows, and are screwed on to the edges of the doors and to the rebates in the frames.

(c) *Rising Butt Hinges:* (Fig. 338.) In this type the wearing surfaces of the two leaves of the hinge are formed as helical curved surfaces. This causes the door to rise as it is opened, and thereby to clear any small obstruction such as carpets, etc. It also makes the door close automatically.

(d) *Back Flap Hinges:* (Fig. 333.) This is used where the shutters to be hung are thin and do not permit the fixing of the hinges to the edges.

Besides these types there are other types of hinges used on doors and windows, and additional information on this point can be obtained by reference to catalogues of firms dealing in hardware.

(2) *Fastenings and Locks:* Fig. 336 shows a tower bolt. A barrel bolt is similar to it. In the former type, the bolt passes through two or three staples, whereas in the latter type, staples are substituted by a continuous barrel.

Fig. 340 shows a flush bolt. Such bolts are let into the doors either upon a face or on the edge, and flush with the surface. They are used where the projecting tower bolt would be objectionable.

Fig. 347 shows an *aldrop bolt* which is fixed on external doors where a padlock is to be used.

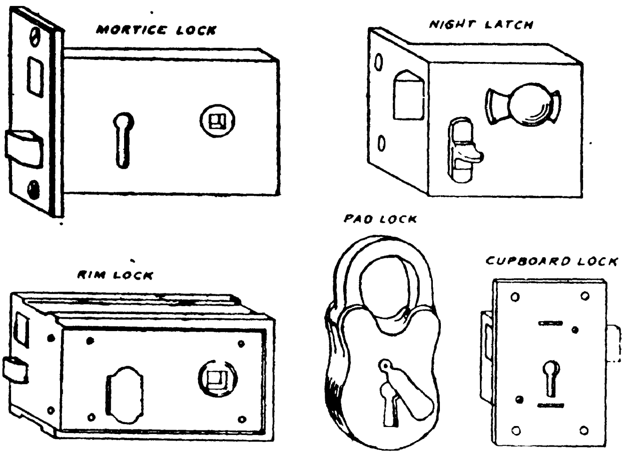
Fig. 343 shows a *Norfold latch* which consists of a lever pivoted at one end, with a hasp and staple fitted on the inside of the door, actuated by a trigger passing through the door and pivoted in the upper part of a vertical bow-handle. The latch can be released by pressing the trigger.

Fig. 350 illustrates a *mortise lock* which is fixed in a mortise formed on the edge of a door.

Fig. 352 shows a *rim lock* which is fixed on the face of a door, and has a projecting flange or rim passing across and screwed on its edge.

Handles are of various types such as bow, knob, or lever pattern. Common types of bow handles are illustrated in Figs. 344 to 346.

Figs. 350. 351.



Figs. 352. 353. 354.

Fig. 342 shows a hook and an eye which can be effectively used for keeping the shutter open. The hook is fixed to the sill of the door or window frame, and the eye is fixed to the bottom rail.

Fig. 335 shows an *espagnolette bolt* which is an extension bolt, useful for tall doors and windows, the top of which cannot be easily reached.

Location of Doors and Windows: Doors should be so located that they permit the maximum use of the accommodation in a room, and maintain privacy without sacrificing convenience. As a rule, particularly in residential quarters, doors should not be located in the centre of a room, but should be placed near the end.

Windows: The position of windows will depend on the orientation of a building. An attempt should be made to get the most of the effective light from the windows in the north wall,

as those in the south wall are subsidiary, and are mainly for ventilation. It should be remembered that the restorative and recuperative value of light is almost equal to that of fresh air. This should specially be borne in mind in the case of factories, workshops, and schools. Full advantage should be taken of sunshine, which is of real value in ventilation, as it sets up convective currents in the air. It is also a powerful disinfectant.

The sills of windows should be kept 0·75 m. to 1 m. (2′-6″ to 3′-6″) above the floor, and the window should extend nearly to the ceiling.

The area of windows and ventilators should be between 1|10 to 1/5 of the floor area of the room. The latter value is adopted for chawls, dormitories, factories, schools and hospitals. The former value is adopted for residential buildings, in which the floor space per capita is more.

Questions for Revision on Chapter VII.

(1) What is brick-nogging? What precautions must be taken so that brickwork should not get loose? In what respects are reinforced brick partitions superior to brick-nogged ones?

(2) Describe any two methods of plaster-on-metal lath partitions. What is done to make such partitions stiff and rigid?

(3) What is the difference between a common and trussed partition?

Questions for Revision on Chapter VIII.

(1) What is the difference between a ledged-and-braced and a framed, ledged and braced door? What should be the direction of the braces and why?

(2) Why are bottom and lock rails wider than the top rail?

(3) What is a diminishing stile, and what is the object? Sketch a joint at diminishing stile.

(4) What are the advantages of a flush door?

(5) What is a dormer window and where is it used?

(6) Briefly describe: (a) a clerestorey window, (b) a lantern light, (c) a bay window, (d) a revolving door.

(7) What considerations would guide you in locating the positions of doors and windows in a house?

(8) What should be the relation between floor area and window area in a public building such as a factory, school, etc.?

LINTELS AND ARCHES : 9

Openings in walls for doors, windows, cupboards, etc. must be bridged over so as to support the load of the wall above them. This is accomplished by either a lintel or an arch. A lintel is more convenient than an arch as it spans an opening like a beam. An arch imposes a horizontal thrust which tends to push the

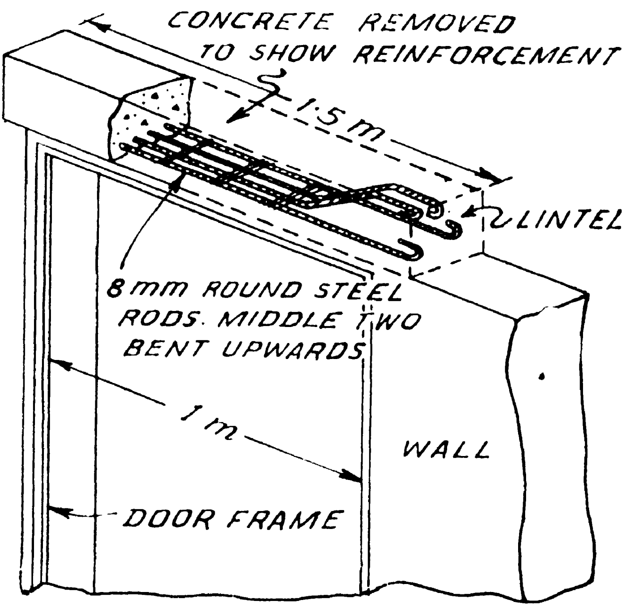


Fig. 355:

R. C. C. lintel. Isometric view, showing part of concrete removed to show how steel rods are bent.

walls laterally. An arch must, therefore, be introduced with caution if the opening be close to the end of a wall, affording a small abutment, unless a metal tie rod, binding the two ends of the arch together, is provided.

Arches receive certain particular names, derived from the function which they perform. There are two such types, viz., (1) *Relieving arch,* and (2) *Inverted arch.*

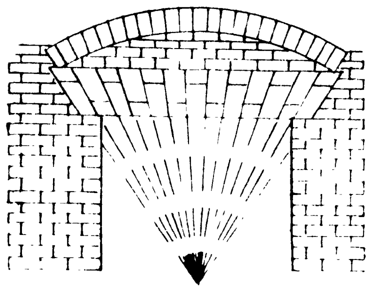


Fig. 371:
Flat arch with a relieving arch on top.

A relieving arch, or a *discharging arch,* is one formed over a lintel to relieve the latter of the superincumbent weight. (See Fig. 373.)

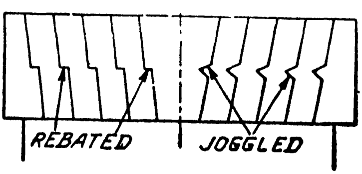
An inverted arch has its crown below the springing and centre above the springing. These arches are mainly used for distributing the load of the piers on the foundations. (See Fig. 9, p. 18).

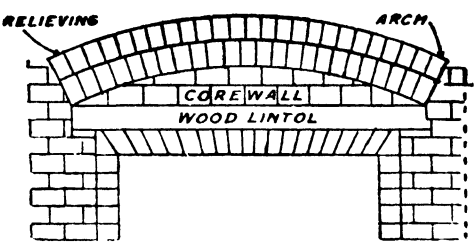
Voussoir arches are either of stone, brick, or pre-cast concrete blocks.

Stone Arches: Stone arches are of two kinds, viz., (a) Ashlar arches, and (b) Rubble arches.

Flat arches of stone are sometimes further strengthened by "rebated or joggled joints". (See Fig. 372).

Ashlar Arches consist of properly cut and dressed wedge-shaped stones of the full thickness of the arch set in lime or



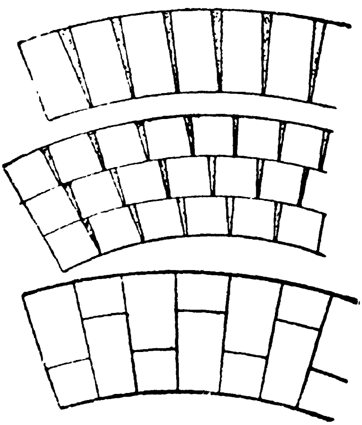


Figs. 372, 373:
***Left*—A flat stone arch, showing two different forms of joggled joints.**
***Right*—A flat brick arch with a wooden lintel and a relieving arch on top.**

cement mortar. For working out the size of the voussoirs and the keystone, the full size arch is set out on a level and plastered platform, and the various voussoirs of equal dimension and keystone of a little larger dimension, are marked on these, leaving

between the adjacent voussoirs a clear gap equal in width to the thickness of the joint. This has to be done by trial and error, and when the final solution is obtained, templates of iron sheet corresponding to the voussoirs and the key, are cut, and the stones are dressed to these templates. Alternatively, the dimensions of the voussoirs and the key can be obtained analytically by finding out the centre line length of the arch from which the aggregate thickness of all joints is deducted. The balance is then divided by the total number of voussoirs to be provided in the arch. The method also requires a preliminary assumption as to how many voussoirs (including the key) are to be provided. As an exercise, the reader should find out for himself the number and size of voussoirs of a stone arch of 3 m. (10 ft.) span and 0·75 m. (2½ ft.) rise.

Rubble Arches: These consist of rubble stones roughly hammer-dressed to the required shape and laid in lime or cement mortar. In this type it is not necessary that all the stones be of the same size. As a rule, up to 40 cm. (15 in.) thickness of the arch, all stones used are of the full depth of the arch ring. But arches having a greater thickness may be made up in two stones.



Figs. 374—376:
A rough brick arch with whole bricks on edge has very wide joints on top (Fig. 374); so half-brick rings are constructed. (Figs. 375). Fig. 376 shows a gauged arch.

As the dressing of ashlar arches is more accurate, they are definitely stronger than rubble arches which have to depend for their strength on the mortar used. The bond in ashlar arches is more perfect. Rubble arches are occasionally used for concealed work.

Brick arches are classified into three varieties, according to the quality of workmanship and the bricks used, viz., (a) *Rough brick arches,* (b) *Axed* or *rough-cut arches* and (c) *Gauged arches.*

(a) *Rough Brick Arches* are constructed with ordinary

bricks that are neither cut nor dressed to the wedge shape. The length of the extrados being greater than that of the intrados, the joints become wider near the extrados. These are generally constructed in half-brick rings, and are only used for concealed work. They lack in strength and should not be used except in unimportant places.

(b) *Axed or Rough-cut Arches* are constructed with bricks roughly cut to the wedge shape by means of a bricklayer's axe. They are unsuitable for exposed work due to the rough appearance of their joints.

(c) *Gauged Arches* consist of bricks cut and accurately dressed to the wedge-form so as to give fine, truly radiating joints. Specially made bricks known as *Cutters* or *rubbers* are used. These bricks can be easily cut with a brick cutting saw, and the surface can be finished by rubbing with a stone or a file.

Bonds in Brick Arches: In constructing brick arches, it should be observed that each joint radiates very approximately to the centre of curvature. The direction of the joint can be obtained by means of a wooden template about a foot long, with its underside cut to the required curvature of the intrados and its sides perpendicular to the intrados. This wooden template is placed on the centering so that the side corresponds to the direction of the joint.

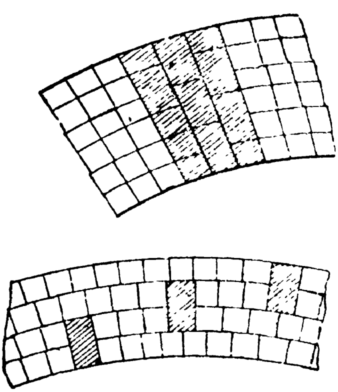
There are two principal systems of bonds in brick arches:

1. Concentric rings of whole or half bricks (Fig. 375).
2. Alternate rings of whole or half bricks (Fig. 376).

In the first method, the bricks are laid as headers or stretchers in concentric rings and the average thickness of the joint in this method is the minimum, provided continuous radial joints are not aimed at. Consequently, more bricks and less mortar are required. It is perhaps, the easiest, and therefore, the most common method of construction, especially when stretcher rings are used.

If continuous radial joints are aimed at, the thickness of the joints near the extrados will be very large as compared to that at the intrados (Fig. 374). This difference in the thickness would be increased with the increased thickness of the arch. Therefore, continuous radial joints are not advisable for thick arches.

This method of laying the arch in concentric rings, even with non-continuous radial joints, is not recommended for longer spans, the usual limit of span being 10 m. (30 ft.) since the line of pressure, in passing from the extrados to the intrados, tends to separate the rings and the whole pressure might momentarily be thrown on one ring. In such a case the ring might probably be crushed and the pressure transferred to the next ring which also might give way, and this might lead to complete collapse of the arch.



Figs. 377, 378: Bond blocks are used in Figs. 377 and 378, and two consecutive rings are bonded in Fig. 378.

To avoid the objection to concentric ring arches mentioned above, it is a common practice to provide keys made of blocks of stone or of blocks of bricks constructed in a different bond, at intervals. The positions of the keys are fixed at the places where the radial joints of the various concentric rings become continuous (Fig. 377.). These keys are also known as *bond blocks.* An alternative method of producing the same effect consists in introducing headers so as to unite the two half-brick rings where the joints of two such rings coincide. To make this method most effective, consecutive pairs of rings are continuously united throughout the thickness of the arch (Fig. 378).

The second method of laying brick arches consists of bricks laid alternately as headers and stretchers in section with a continuous radial joint. The plan consists of alternate courses of headers and stretchers similar to the English Bond. The average thickness of the joint in the bond is greater, and consequently, more mortar, and less bricks are required. This bond is preferred for its appearance, and is quite often used for facing rings in exposed work.

Arches of Concrete Blocks: Arches of cement concrete blocks are similar to ashlar arches except that, instead of stone voussoirs, pre-cast concrete blocks are used.

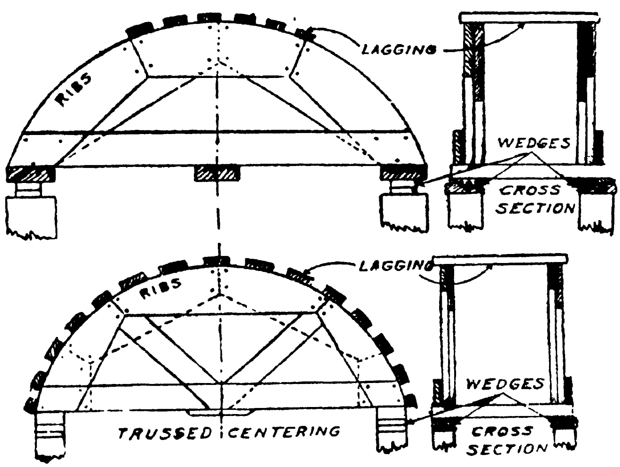
The casting of the blocks is done in accurately made moulds

at the site of construction so as to minimise the lead. The blocks, after they are cast, are allowed to remain there for a couple of days, after which they are removed to the curing pond where they remain under water for about 20 days. The blocks are then ready for use. The mixture used for the concrete depends on the strength required, but usually the proportion of concrete used is 1 of cement to 2 of sand to 4 of broken stone.

This type of construction is extremely suitable for places where stone of sufficiently large size, and trained labour for the construction of monolithic concrete arches are both unavailable and there is ample good sand in river-bed. However, the type can only prove to be economical on big works, as otherwise, the cost of the moulds, etc., would greatly influence the total cost of the work.

Arches of pre-cast concrete blocks have been successfully used for many important bridges in India.

Construction of Voussoir Arches: After the voussoirs are prepared as explained on page 170, a temporary structure is



Figs. 379—382:
Wooden centres to support an arch till the mortar sets. The upper is a simple ribbed centering and the lower is trussed. The figures on the right are cross sections.

erected in the opening over which the arch is to be constructed. This temporary structure, which is known as *centering,* is intended to support the voussoirs during construction. Centering

is usually of timber, but occasionally mild steel trusses are used for this purpose. Centering made of mild steel trusses is only suitable where a number of similar arches are to be constructed and where the magnitude of the work is sufficient to warrant the high initial cost of mild steel trusses.

Wooden centering consists of built-up ribs or trusses, the upper surface of which is of the same form as the intrados of the arch to be supported. These trusses or ribs are spaced from 1 m. to 1·25 m. (3 to 4 ft.) apart, and are connected at top by 5 cm. (2″) thick narrow planks. The planking, which is nailed on the top of the ribs or trusses, is known as *lagging*. The ribs or trusses are either supported on corbels projecting from the piers, or on wooden props, and an arrangement for lowering the centering is made by introducing a pair of folding wedges under each end of the truss. Figs. 379, 380 illustrate an ordinary ribbed centering, and Figs. 381, 382, trussed centering.

After the centering is ready, the laying of the voussoirs is started from both the springing points, and the key is the last stone that is fitted in.

For long span arches, it is necessary to ease the centering slightly so as to allow the arch to settle a little and consolidate itself. For facilitating the even easing of the centering of such arches, it is convenient to use sand boxes under the centering trusses. The arrangement is as follows:

A round box is filled to half its depth with very fine dry sand, and a wooden piston is inserted into the box. The truss is supported on the piston. There is a small hole at the bottom of the box which is closed by a plug. When the centering is to be eased, the plug is withdrawn and some sand is allowed to leak from the box. This permits the piston to settle down a little and eases the centering. After the centering is eased, the plug is again fitted in and the centering is allowed to remain until the mortar sets.

Although there is some divergence of opinion as to the period after which the centering should be removed, it is generally agreed that the centering must be completely removed before any masonry is constructed on the top of the arch. If the centering is removed after the masonry on the top is constructed, it is likely that the removal of the centering may cause a little

settlement of the arch, and the movement, when communicated to the masonry on the top, will cause cracks in the same.

A timber centering for arches is shown in Figs. 379 to 382.

For small arches over window and door openings, the centering is made in a much simpler way. A thick plank, equal in length to the span of the arch and as wide as the wall, is supported in the horizontal position, level with the springing line, on two or three props. Brick-bats are arranged on this plank to give the rough shape of the intrados. A plaster of mud is then applied on the top of the brickwork conforming to the shape of under-surface required for the intrados.

Thickness of Arches: The thickness of arches may be determined by any one of the following rules:

1. For single, segmental arches $T = \sqrt{0 \cdot 045 \times \text{radius in meters}}$. For single, semi-circular arches, the coefficient $0 \cdot 045$ should be increased to $0 \cdot 07$.

2. For segmental arches in series: $T = \sqrt{0 \cdot 064 \times \text{radius}}$ in meters. For semi-circular arches, in series, the coefficient $0 \cdot 1$ should be taken.

3. For high-way arched bridges, the following formula is commonly adopted:

$$T = \sqrt{0 \cdot 003 \text{ span} \left(\frac{\text{span}}{\text{rise}} + 1 \right)} + 0 \cdot 04$$

In all the above formulæ T is in meters.

Example 1 : Determine the thickness of an arch ring for a span of 3 m. The rise of the arch is $0 \cdot 75$ m.

Solution: The radius R of the intrados is given by the following equation :—

$$(1 \cdot 5)^2 = 0 \cdot 75 \, (2R - 0 \cdot 75)$$

$$\therefore \quad R = \frac{3 \cdot 75}{2} = 1 \cdot 875 \text{ m.}$$

$\therefore$ From the first formula, assuming that the value of the constant is $0 \cdot 045$, the thickness works out to

$$T = \sqrt{0 \cdot 045 \times 1 \cdot 875}$$
$$= \sqrt{0 \cdot 08438}$$
$$= 0 \cdot 295 \text{ m.}$$
$$= 29 \cdot 5 \text{ cm. say } 30 \text{ cm.}$$

Example 2 : Find the thickness of an arch ring for a span of 5 m. and a rise of 1 m.

Solution: Using formula (3) above

$$T = \sqrt{0 \cdot 003 \times 5\ (5+1) + 0 \cdot 04}$$
$$= \sqrt{0 \cdot 13} \quad = 0 \cdot 36 \text{ m.}$$
$$= 36 \text{ cm.}$$

Questions for Revision.

(1) Why have R.C.C. lintels superseded all other forms? What makes reinforced brick lintels superior even to R.C.C. lintels?

(2) Define by means of a sketch the following parts of an arch: (1) Spandrel, (2) Springer, (3) Abutment, (4) Intrados, (5) Pier, (6) Skewback, and (7) Haunch.

(3) When and where are the following used? (a) Inverted arch, (b) Relieving arch.

(4) How is a bond in brick arches maintained?

(5) Sketch a wooden centering for a segmental arch of 2·5 m. (8 ft.) span, ¼ rise showing the parts with their names.

(6) Describe how the centering below a large span arch is relieved.

(7) Calculate the thickness of a ring of a masonry arch for a span of 6 m. (20 ft.)

STAIRS AND STAIRCASES : 10

STAIRS are steps arranged in a series for the purpose of giving access to different floors of a building. Stairs inside a building are generally accommodated in special apartments called staircases.

As a stair is frequently the only means of communication between the various floors, the position of stairs needs careful consideration. In a dwelling house the staircase should be near the front entrance, but screened from it for privacy, if some of the rooms on the upper floor are not strictly private. In a public building, its position should be obvious from the main entrance. The staircase, in both cases, should be placed centrally, so that the doors of the principal apartments on each floor are near to it. It is generally desirable for economy of space, provision of ventilation, and ease of construction, to place the staircase against a wall. All staircases should be property lighted and well ventilated.

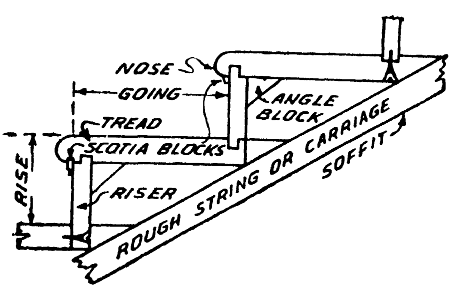


Fig. 383:
Showing the names of the different parts in a stair.

Stairs may be either of timber, stone, brick, concrete (plain or reinforced), mild steel, or cast iron.

Before entering into the details of construction, it will be convenient to deal with the technical terms used in connection with stairs.

Technical Terms : (Fig. 383).

(a) *Tread:* The horizontal upper portion of a step. (This term is often used to represent the *going.*)

(b) *Riser:* The vertical portion of a step.

(c) *Rise:* The vertical distance between the upper surfaces of two successive steps.

(d) *Going:* The horizontal distance between the faces of two successive risers.

(e) *Fliers:* General steps in a staircase, rectangular in plan.

(f) *Winders:* Steps used for changing the direction of the stair, usually triangular in plan.

The central winder of series is called the *kite winder* on account of its shape.

Landings: Flat platform at the head of a series of steps. Such a platform, extending right across a staircase is called a *half space landing,* and that extending only half across a staircase, is called a *quarter space landing.*

Flight: A series of steps between landings.

Nosing: The outer projecting edge of a tread, usually rounded (Fig. 383).

Line of Nosing: An imaginary line connecting the nosings, and parallel to the slope of the stair.

Newels: Posts used at the junction of a flight with a landing or with other flights, or at the foot of a stair (Fig. 391).

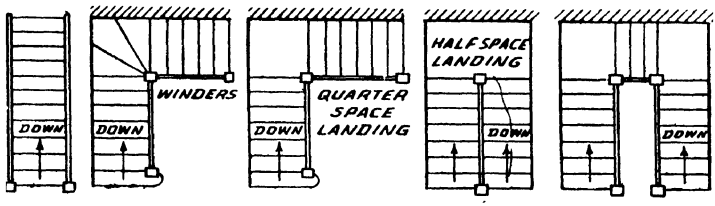
Curtail Step: The lowest step of a flight when finished at the outer end in the form of a scroll.

Different Forms of Stairs: A *Straight Stair:* (Fig. 384). This is one in which all steps lead in the same direction. Such a stair is suitable for a long narrow staircase. It should consist of one flight only, or in special circumstances, of two flights, but not more. If there are two flights, the landing between them should not be less in length than the width of the stair.

A Dog-legged Stair: (Fig. 387). One in which the succeeding flights rise in opposite directions, the outer end of the steps in an upper flight being vertically over the outer end of those in the flight it succeeds. Flights may be separated by (a) a half space landing, (b) a quarter space landing and one set of winders, and (c) two sets of winders and no landing. These methods are given in order of merit. The last method should be avoided as far as possible, since it makes the stair too steep and dangerous near the newel, and also involves constructional difficulties.

An Open Newel Stair: (Fig. 388). One in which there is a rectangular well, or opening, between the backward and forward flights. The width of the staircase would, therefore, be twice the width of the stair plus the width of the well. This

Figs. 384 385 386 387 388



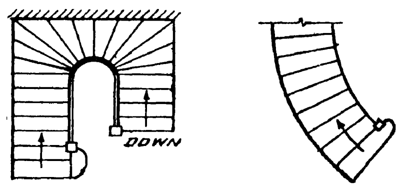


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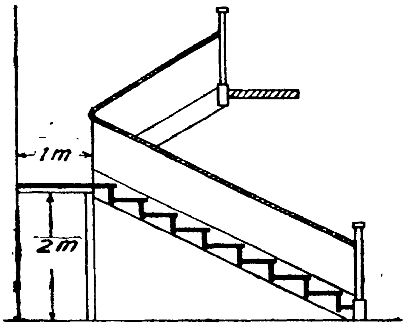
Fig. 384: Straight.
Fig. 385: Quarter turn with winders.
Fig. 386: Quarter turn with quarter space landing.
Fig. 387: Dog-legged with half space landing.
Fig. 388: Open newel with quarter space landing.
Fig. 389: Geometrical.
Fig. 390: Circular.

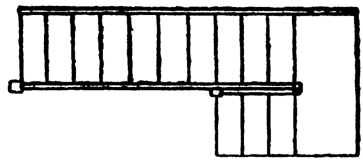
is a convenient form of stair, and the well allows of top lighting. If the space for a stair is limited, a short flight is introduced on the narrow side of the well with two quarter space landings on either side.

A *Geometrical Stair:* (Fig. 389). One in which the well is curved between the backward and forward flights. The change of direction is obtained by winders radiating from the centre of curvature of the curve between the flights. It will be noted that the winders in a geometrical stair have a certain width even at the inner edge, and they are therefore, more convenient to negotiate than winders in a newel stair.

Circular Stair: (Fig. 390). These stairs are usually of stone or R. C. C. or iron, and are contained in a circular stair-

case. All steps are winders and are supported by a newel at the centre, or there may be a circular well hole. When all the steps radiate from a central newel, they are termed spiral stairs. Iron spiral stairs are not usually enclosed in a staircase, and are very suitable for back door entrances as they occupy very little room.





Figs. 391, 392:
Sectional elevation and plan of a dog-legged staircase.

Planning and Designing of Stairs: Given the space available and the height between floors, in order to design the stair, it is necessary to determine its form and the approximate points at which the first and last riser can be placed, having regard to the position of doors, openings, corridors, and windows. A convenient height for the rise which should be between 12 cm. and 20 cm. (5″ and 8″) may be assumed, and the height between floors, divided by the height of each riser, will give the total number of risers required. The treads will be one less in number than the risers, and should be between 25 cm. and 35 cm. (9″ and 13″) in width. The *going* may be ascertained from one of the following rules:

(1) Going $\times$ Rise, both in cm. $=$ 400 to 410 cm.

(2) 2 $\times$ Rise $+$ Going, in cm. $=$ 60 cm.

(3) Take 300 mm. (12″) going and 140 mm. (5½″) rise as a standard, and for each 25 mm. (1″) subtracted from the going, add 12 to 13 mm. (½″) to the rise.

In dwelling houses 25 cm. $\times$ 16 cm. (10″ $\times$ 6½″) and in public buildings 27 cm. $\times$ 15 cm. or 30 cm. $\times$ 13 to 14 cm. (11″ $\times$ 6″ or 12″ $\times$ 5½″) are the usual dimensions. In factories, the going must not be less than 25 cm. (10″) and the rise not more than 19 cm. (7½″); while in theatres, the

corresponding figures are 27 cm. and 15 cm. (11″ and 6″) respectively. It should be noted that the rules given above are merely as a guide, and the actual dimensions depend on the circumstances. It is, however, important that whatever rise and tread are once adopted, they should be maintained constant throughout the stair, or at least in one flight.

The width of a stair should not be less than 85 cm. (2 feet 9 inches) so that a person going down can pass a person going up. In tenement buidings 105 cm. (3 feet 6 inches) should be regarded as the minimum width of a stair.

Head Room Over a Stair: A minimum head room of 2·1 m. (7 feet) should be provided. (See Fig. 395).

Length of Flight: A flight should not contain more than 12, or, at the most, 15 steps, otherwise it becomes tiresome to ascend and somewhat difficult to descend. A flight should also not contain less than 3 steps, as fewer steps than this are apt to prove disconcerting in use.

Winders: As far as possible, winders should be avoided; but if the area of staircase is limited, and winders have to be used, they should be placed near the lower end of the flight; for, if one happens to slip, while descending, from a winding step the fall will be from a small height. Only three winders should be used in a quarter space so that the *going* of the winders becomes equal to the general going of the stair on the part of the winders most used, i.e., about 45 cm. (18″) from the newel. (See Fig. 385).

Landings: Landings should not be less in width than the width of the stair in which they occur.

Stairs of Different Materials: Wooden Stairs: These are lighter than those of any other material, and are very commonly used in dwelling houses. The chief objection to them is that they are liable to be attacked in the early stages of a fire, and may thus prevent escape from the upper floors. If, however, the timber used is teakwood of at least 5 cm. (2″) finished thickness in all parts, they are sufficiently fire-resisting to enable the occupants to escape within a reasonable time.

The steps of a wooden stair are supported at each end, and frequently at intermediate points, by sloping wooden members called *strings* or *stringers.* The strings are supported on newels, trimming joists, or pitching pieces. Strings are of two kinds, viz., Cut strings and Housed strings.

Cut Strings have their upper surface notched to conform to the tread and riser of each step, their lower edge being parallel to the slope of the stair (Fig. 393). In all but the commonest work, the vertical portion of the notch is mitred (See next chapter); the end of the riser also being mitred, fits against it, thus concealing the end grain of the wood. This is only done of the outer string which, when treated like this, is called a cut and mitred string. Cut strings in newel stairs are mortised and tenoned into newel posts at top and bottom. The thickness of an ordinary cut string is 4 to 6 cm. (1½ to 2½ inches.)

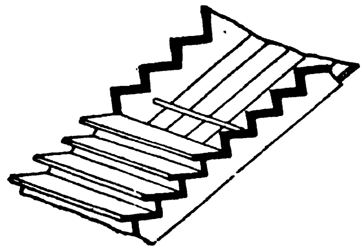


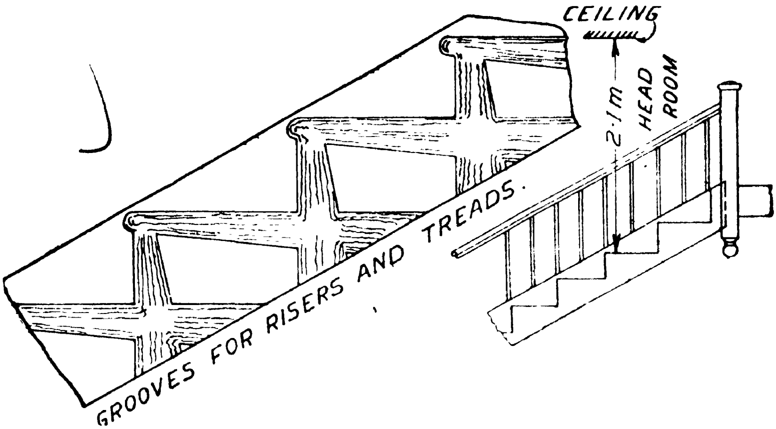
Fig. 393:
A staircase with cut strings.

Housed Strings, also known as closed strings, have both their upper and lower edges parallel to the slope of the stair. Grooves or housings are cut in their inner sides to receive the ends of the treads and rises (Fig. 394). The housings are sloped at the lower side of the tread and the inner side of the riser to receive wedges which should be of hard wood. These hold the tread and riser firmly in position. Against walls, housed strings are nearly always used. In this position they are called *wall strings.* Closed outer strings are oftentimes moulded and panelled to produce an architectural effect.

Rough Strings or Carriage: When the stair is so wide that the steps require an intermediate support, this is given by what are called rough strings. Rough strings also serve the purpose of supporting the laths (strips of wood on which plaster is applied) where the soffit of the stair is to be plastered. A rough string supporting a step is shown in Fig. 393.

Wreathed Strings: These are required in the construction of wooden geometrical stairs. Steps of wooden stairs are formed of boards. The treads are usually 4 cm. (1½″) thick, and risers are 2·5 cm. (1″) thick. The tread is made to project slightly 1·5 to 2 cm. (about ½ to ¾ in.) beyond the face of the riser so as to increase the available width of tread. This projection is known as the nosing. The nosing is usually rounded off or otherwise finished with a moulding.

The methods of jointing together treads and risers are shown in Fig. 396. On the left hand side of the lowermost step in the figure, the riser is jointed to the tread on its top (1) by a tongue



Figs. 394, 395:
Fig. 394 shows a housed or closed string in elevation. The grooves are tapered to receive wedges for fixing the treads and risers firmly.
Fig. 395 shows the head room on the top of steps.

on the top of the riser fitting into a corresponding groove on the underside of the tread, (2) by an angle block in the corner between tread and riser, (3) by a 16 mm. × 28 mm. (5/8″ × 1 1/8″) scotia glued into a groove in the bottom of the nose of the tread. The riser of the step above it is tongued both at top and bottom into treads; besides, there are angle block and scotia. The riser of the topmost step has its bottom housed into a groove on the top of the tread and is further strengthened by screws.

Winders: Winders are formed by cantilevering out the risers of substantial thickness from the staircase wall, and these are used to support the treads. The outer end of the cantilevered riser is housed into the newel post. The front end of the tread rests directly on the riser, while the rear end is fitted into a groove cut into the riser of the upper step. (See Fig. 397.)

Alternatively, winders may be supported by means of bearers, built into the wall at one end, and framed into the newel at the other (Fig. 397). The back of the bearer is flush with that of the riser immediately over it. Cross bearers, to support the treads, are framed between the risers and the bearers behind them.

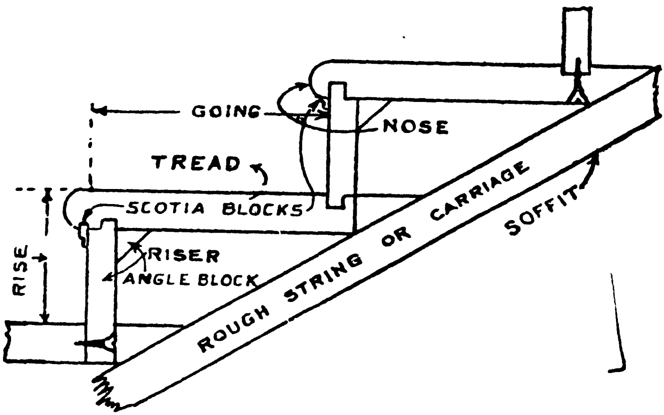


Fig. 396:
Showing different methods of jointing risers to treads.

In a geometrical stair, the winders and bearers are framed into the wreathed string, and have cross bearers as for newel stairs.

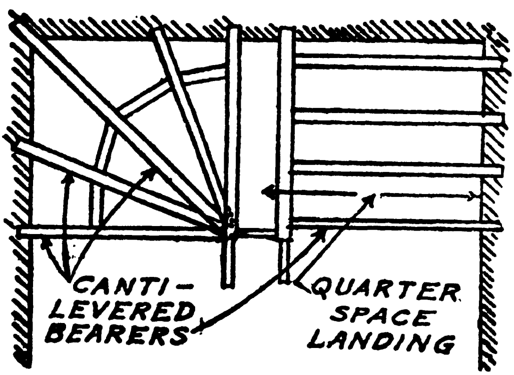


Fig. 397:

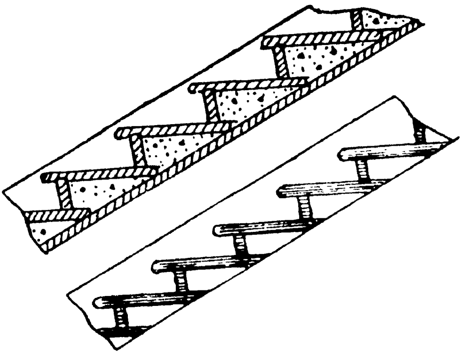
The winders on the left hand side are formed by risers with one end embedded into the wall and the other free. The quarter space landing on the right hand side is also supported by canti-levered bearers.

Landings: In forming half-space landings, a trimmer is fixed across the width of the staircase. It supports the bridging joists which are tenoned into the trimmer at one end, and are supported on the wall at the other. The trimmer also takes the ends of the carriages or string of the up-and-down flights, and the newel notched over it.

In forming a quarter space landing, the pitching piece is built at one end into the wall, and at the other end, it is housed

into the newel, which may either be hanging or supported on the floor. In the former case, the pitching piece is required to be designed as a cantilever, and may have to be strengthened by means of a bracket on the under side. The pitching piece supports the bridging joists for the landing.

In the variety of wooden stairs illustrated in Figs. 398 and 399, lime concrete is poured into the stair box erected in position, consisting of two cut strings on either side, boarding supported by a rough carriage at bottom, and risers fixed in their respective positions. When the concrete has set, the top is levelled, and boards to form treads are screwed.



Figs. 398, 399:
Wooden stair filled with concrete to make it sound-deadening and better fire-resisting.

This forms a semi-fire-proof wooden stair which has one more advantage, viz., it is not as noisy as the usual hollow wooden stair.

Stone Stairs: Except for its weight, stone is a suitable material for constructing stairs. Compared to wood it is harder, more durable, less likely to decay, and more fire-resisting. Sandstones, as a class, are the best for this purpose, both as regards durability and fire-resisting properties.

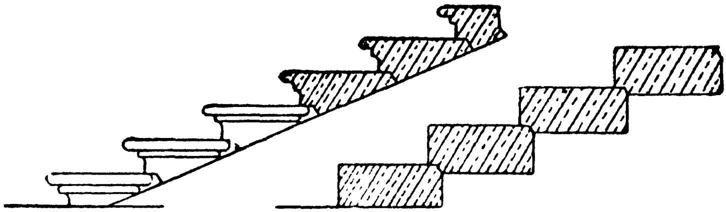
Being heavy, stone steps require strong supports. Stone is, therefore, generally used for external stairs.

Construction: The two main types of stone steps are:

(1) Square steps consisting of solid rectangular blocks.

(2) Spandrel steps formed of triangular blocks of stone.

Square Steps are shown in Fig. 401. They have a rebate cut at their lower corner into which fit the square upper edges of the steps below. The minimum lap of the upper step on the lower one is 2·5 cm. (1″). Square steps are cheaper than spandrel steps as the labour in cutting and dressing the stone to a triangular shape is saved.



Figs. 400, 401:
Spandrel and square steps respectively.

Spandrel Steps are shown in Fig. 400. The sloping soffit of spandrel steps gives a better appearance and a greater head room. Each step is rebated to fit on that below, the back of

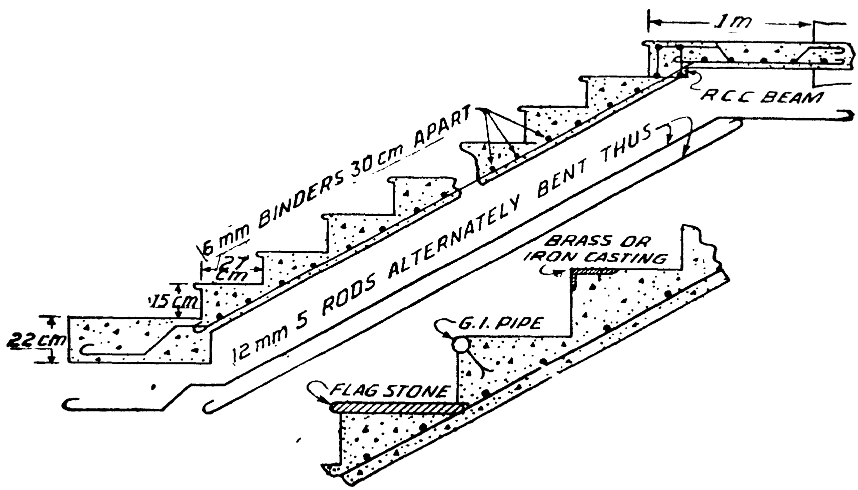


Fig. 402:
Shows a longitudinal section of a flight of R.C.C. stairs, showing reinforcement.

Fig. 403:
Shows how the steel rods are bent.

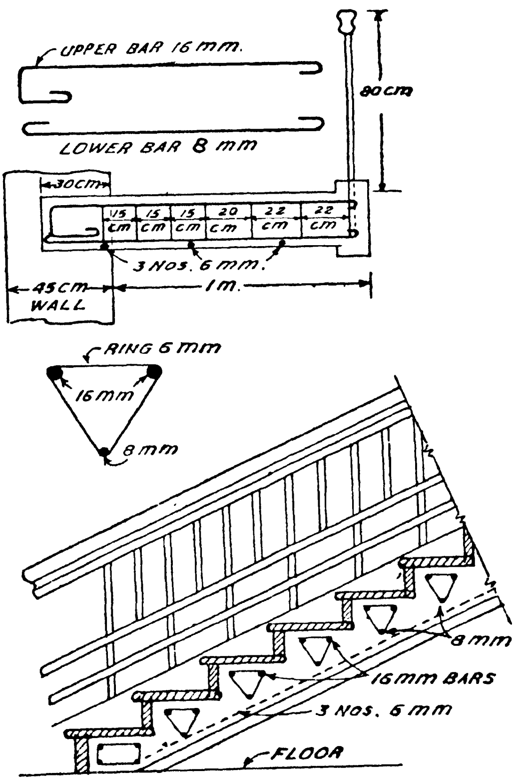
Fig. 404:
Shows an enlarged section with three different treatments for protecting the edges of steps.

the rebate being at right angles to the soffit. This avoids acute angles at the edges, and ensures a direct thrust. The distance from the internal angle between the tread and the riser should not be less than 5 cm. (2″) for stairs up to 105 cm. (3′-6″)

wide, and for every additional 30 cm. (foot) width, this distance should be increased by 12 mm. (½ inch.) The ends of the spandrel steps, which are built into the wall, are invariably left square so as to get a horizontal seating.

Landings for stone steps are of stone slabs, the thickness of which varies from 8 to 15 cm. (3″ to 6″) depending on the circumstances.

Support for Stone Steps: Stone steps may be supported by (a) building into stone walls at both ends, (b) being built into a wall at one end, and unsupported at the other (forming cantilever steps), (c) being built into a wall at one end and supported at the other by steel work, or by (d) being supported by the steel work, at both ends.



Figs. 405—408:
Details of a cantilevered R.C.C. stair.

(a) The minimum wall hold for steps of this class must be 12 cm. (4½″). For stairs wider than 1·2 m. (4 feet), the hold must be increased to 25 cm. (9 in.)

(b) For this class of steps, the minimum wall hold must be 25 cm. (9 in.) and the length of cantilever steps must not exceed 1·2 m. (4 feet).

(c) The wall supports of this class are the same as those for class (a). The outer steel supports are of rolled steel either L or I sections connected to I section trimmer by an angle cleat connection.

(d) Supports for this class of steps are similar to the outer supports for class (c) steps.

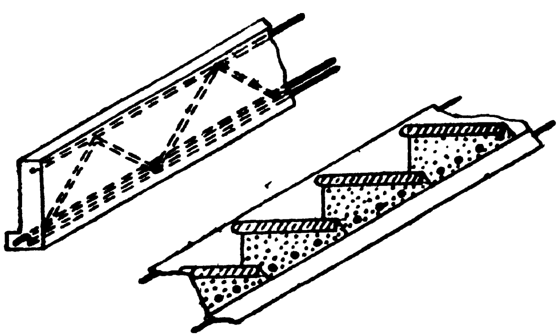
Brick stairs are not commonly used, and will not be dealt with in detail. The tread for brick stairs is a little less than the length of the brick, i.e., a little less than 22 cm. (9 in.) If the rise required is more than the height of a brick placed on edge, a tile-tread may be used to increase it.

Concrete Stairs: Concrete stairs are usually made of cement concrete 1 : 2 : 4. Concrete stairs are now commonly used in places where formerly stone stairs would have been adopted. Steps for concrete stairs are invariably of the spandrel type, and are supported in much the same way as stone steps, and the remarks as to the bearing, etc., apply equally to concrete stairs. Concrete stairs may be cast *in situ,* or pre-cast steps may be used.

Concrete stairs are more fire-resisting than stone stairs.

Reinforced Concrete Stairs: This is the commonest type of stairs in modern buildings. R. C. C. stairs are usually cast *in situ,* but occasionally pre-cast steps may be used. Figs. 402 to 410 show different varieties of R. C. C. stairs and their details.

Iron and Steel Stairs: Iron and steel stairs are not commonly used in residential buildings, but they are frequently adopted in factories, godowns, etc. The steps for these stairs are of cast iron, and are supported on stringers of rolled steel sections either channel or I. The vertical supports for these stairs are also of I-section R. S. joists continuous from the bottom of the stair to the top.



Figs. 409, 410:
R.C.C. pre-cast stair. Elevation of a right-hand string and vertical section through steps.

Fig. 411 shows a stair made by combining steel and concrete. Three I-beams or two angles on sides and a T-iron between, of the necessary sections and lengths are placed in posi-

tion at the necessary inclination, and rigidly fixed both at bottom and top and also in the middle by through bolts to keep them at the proper distance apart. Then 4 cm. ($1\frac{1}{2}$ in.) thick flagstones are placed between them to rest on their flanges as shown in Fig. 411, and cement concrete is placed on them so as to form an inclined slab of joists filled with concrete. On this, either monolithic concrete steps may be cast, or bricks laid to form steps of the stair.

Winders for spiral stairs are of cast iron, having the tread and riser cast in one piece with a circular eye at the inner end. These steps are threaded on to a vertical mild steel rod. The steps are designed in such a way that each step supports the one above it.

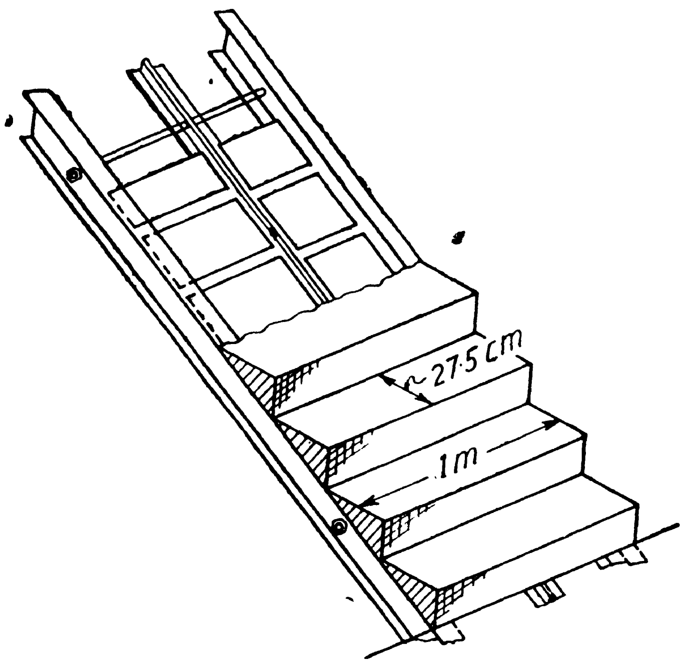


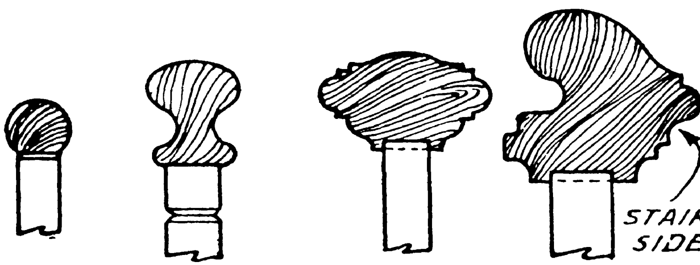
Fig. 411:
Steel and concrete (or brick-work) stair.

Balustrade: A balustrade consists of a hand rail and balusters, and its object is to serve as a protection and support.

Balusters of wrought iron are used for stone, concrete, and iron stairs, whereas timber balusters are optionally used for timber stairs. Hand rails should preferably be of hard wood, but occasionally for steel and concrete stairs, mild steel hand rails are also used. Of late, hand rails of chromium-plated steel, tubular or solid semi-circular section, fixed on the top of polished wood have come into use.

The hand rail should be fixed at from 84 cm. (2′-6″) to 90 cm. (2′-9″) above the line of the nosings. For balustrades on landings 86 cm. (2′-10″) may be taken as the minimum height, 90 cm. (3 feet) being the desirable one.

Figs. 412 to 415 show different shapes of wooden hand rails.



Figs. 412—415:
Sections of hand rails.

Balusters should be spaced at not more than 15 cm. (6″) c. to c. In most cases two balusters for each tread are sufficient.

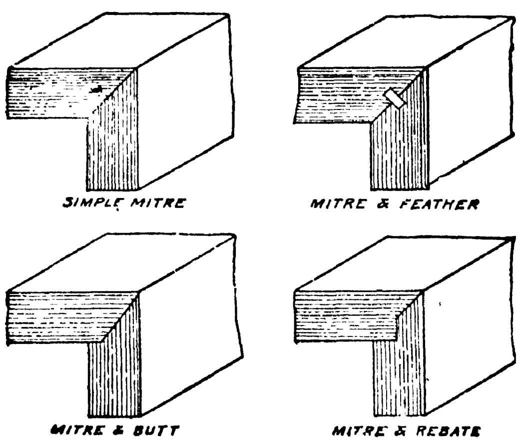
Facing Steps: The object of facing the steps is threefold: Facing is used to resist wear and tear, to prevent slipping, and to enhance the appearance. To fulfil the first two requirements, facing may only be used on the treads, but where appearance is to be improved, the riser also needs to be faced.

The edges of concrete steps are likely to be knocked off, and if broken, are very difficult to repair. In order, therefore, to protect them, three methods are shown in Fig. 404, viz., a brass, cast iron, or steel angle or corner piece with its top chequered to render it non-slippery, a g. i. pipe, or a flagstone with a projecting nose is fixed by suitable means.

CARPENTRY AND JOINERY : 11

In this country, carpentry and joinery are not treated as two separate trades. The carpenter does all the work connected with building, both temporary, such as shoring, scaffolding, centering, etc., and permanent, such as framing and carcassing with beams, joists, wood floors, partitions, roof-framing, etc., and also staircases, making and fitting doors, windows, and all finishing of woodwork, and hardware fittings. Cabinet making, however, is a distinct trade which concerns itself with the making of furniture and furnishing.

Terms Used in Carpentry: *Chamfering* : Taking the edges or arrises off a piece of wood. A sharp edge is never allowed on exposed wood work. It should either be chamfered or rounded. When two chamfered edges are brought together, a V-joint is formed as on the face of a ledged door. (See Figs. 291, 292).



Figs. 416—419:
Different forms of mitre joints.

When the chamfer is not continued to the end of the board, but ends either in another chamfer or a slope, it is called a *stopped chamfer*.

Bead: A semicircular projection formed on edges or surfaces of wood. It is often used in the joints of straight boards as in wooden partitions or plane planked door shutters, the purpose being to cast a shadow over the joint, which, in the event of the

shrinking of the wood, would conceal the unsightliness of the joint.

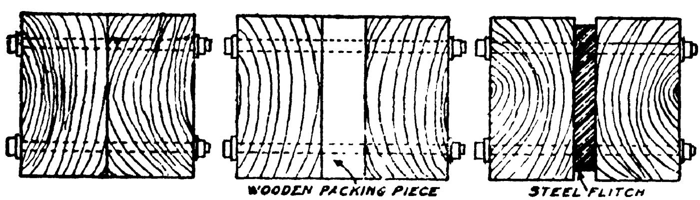
Plough Grooving: The operation of cutting parallel grooves with grain of the wood for decoration.

Rebating: Cutting a rectangular portion from the edge of a board of sufficient depth for another board similarly cut to fit, as in a rebated floor. (See Fig. 534).

Mitring: Joining two boards at an angle. If the angle is a right angle, the corner of each is cut off at an angle of 45° and the two faces are butted. But, as light may show itself through the joint if the wood shrinks, a metre and rebate, or metre and butt joint, is made, as shown in Figs. 416 to 419. The latter is made when the boards are of unequal thickness.

Grounds: Pieces of wood nailed either to wooden blocks, breeze concrete blocks, or plugs in cross joints of walls to form a firm hold or a base to which linings of walls or ornamental moulds can be screwed. They are cut with their surfaces flush with the plaster.

Veneering : Facing or covering the whole or part of the exposed surface of one timber with a thin sheet of another rare or costly timber to enhance the appearance. Veneer may be laid in large sheets, as in plywood, or it may be cut into shaped pieces and inlaid to various designs.



Figs. 420—422:
Flitched beams.

Flitched Beam : Sometimes a wooden beam is cut longitudinally in half, and reversed so that the heart wood portion lies on the outside and then the two pieces are bolted together; this makes it a considerably stronger beam. Sometimes, the two flitches are separated by means of packing or distance pieces of timber and bolted. This is done to increase the width of the

beam, if it is required to carry a wall of greater thickness than that of two flitches together.

Oftentimes a steel plate is inserted between the flitches to strengthen the beam still further. This is called a "steel flitch beam." The two flitches and the steel plate between them are fixed together by 16 or 18 mm. (5/8" to 3/4") bolts placed at 60 cm. (2 ft.) centres at about $\frac{d}{4}$ alternately above and below the neutral axis.

All the three forms of flitched beams are shown in Figs. 420 to 422.

Members forming a wooden framework may be subjected to the following different kinds of stresses :

(1) Direct pull or tension, e.g., tie beams of trusses.
(2) Direct thrust or compression, e.g., posts or struts of principal rafters.
(3) Bending stresses, e.g., beams.
(4) Twist or torsional stresses.

The last kind of stress rarely occurs in structural woodwork, and, therefore, it will not be considered here.

Occasionally, a combination of (1) and (3), or of (2) and (3) may also occur, as in the case of a tie beam with ceiling attached to the underside, or principal rafter in purlin rafter construction.

In designing joints in structural woodwork, provision must be made for the proper transmission of the kind of stress which the member under consideration is subjected to. The general principles to be followed in the design of joints as suggested by Prof. Rankine are as follows :

(1) To cut the joints and arrange the fastenings so as to weaken the pieces that they connect, as little as possible.

(2) To place each abutting surface as nearly perpendicular as possible to the line of pressure which it has to transmit.

(3) To proportion the area of each such abutting surface to the pressure which it has to bear, so that the timber may be safe against injury under the maximum stress which occurs in practice and to form and fit accurately every pair of such surfaces so that the distribution of pressure is uniform.

(4) To proportion the fastenings so that they may be of equal strength with the pieces which they connect.

(5) To place the fastenings in each piece of timber so that there shall be sufficient resistance to the giving way of the joint by the fastenings, shearing or crushing their way through the timber.

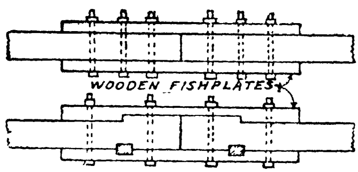
Classification of Joints : (1) Lengthening joints in ties, struts, and members subjected to bending moments.

(2) Bearing joints.

(3) Framing joints.

(4) Oblique-shouldered joints.

(1) (a) *Lengthening Joints in Ties* : Ties can be lengthened either by fishing or scarfing.



Figs. 423, 424:
Butt joints strengthened by wooden fish-plates.

A fished joint, as shown in Fig. 423, is quite efficient and simple, specially where appearance is of secondary importance and strength is the primary consideration. The strength of this joint mainly depends on the bolts and fish-plates, which must, therefore, be made adequately strong. Care should also be taken to see that bolts are not placed too near the ends of pieces. The dependence on bolts may be reduced by indenting the parts together as shown in the upper part of Fig. 424 or by providing keys as shown in the lower part of the same figure.

Scarfed joints are used where neatness is a primary consideration and where the same depth and breadth are to be preserved. Figs. 425 to 430 show the various methods of scarfing.

The joint shown in Fig. 425 is the simplest scarf joint. It depends entirely on the strength of the bolts and it is advantageous to put a continuous mild steel plate on either side to receive the heads of the bolts. The ends of the plate may be bent and let into the timber as shown.

Fig. 426 shows another common scarf joint. It is not as good as the previous one, because the bolts pressing on the oblique faces tend to separate the joint.

Figs. 427 to 429 show the types of scarfs where bolts are not absolutely necessary; but it will be observed that the strength of

these joints is less than half the strength of the piece. The addition of plates and bolts makes these joints quite satisfactory.

Fig. 425.

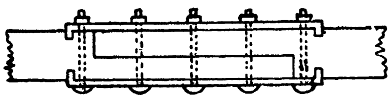


Fig. 426.

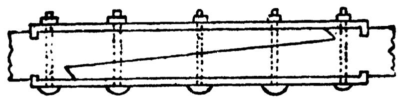


Fig. 427.

Fig. 428.

Fig. 429.

Fig. 430.

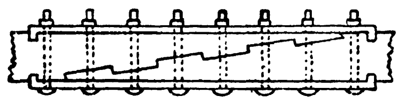


Fig. 429 shows a scarf with notched splays and a hardwood key used to draw the joint close together. This joint is rather difficult to make.

Fig. 431.

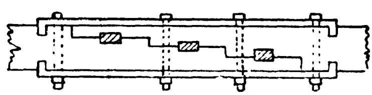


Fig. 432.

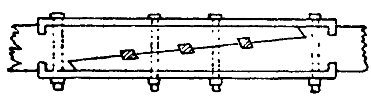


Fig. 433.

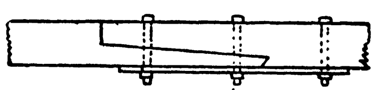
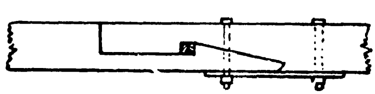


Fig. 434.



Figs. 431—434:
Lengthening joints for beams.

The scarfs shown in Figs. 430 and 431 are generally used where the member is subjected to a considerable stress. These joints are equally strong and suitable for heavily stressed members, but they are rather difficult to execute. The scarf shown in Fig. 432 is a good substitute for either of the types shown in Figs. 430, 431 because it is equally strong and easier to make.

(b) *Lengthening Joints in Compression Members* : These are similar to the lengthening joints in tension members, except that the abutting surfaces must be made perpendicular to the line

of thrust and the joint must be strengthened by buckling. Scarfs in Figs. 427, 428 are suitable for compression members, but it is preferable to have the fish-plates on all the four faces.

(c) *Lengthening Joints in Members Subjected to Bending* : A horizontal beam supported at its ends carrying a vertical load is subjected to a stress which is compressive at the top and tensile at the bottom. A simple joint for such a member is illustrated in Fig. 433.

The portion above the neutral axis is compressed and that below this line is stretched. A square abutment above the neutral axis to transmit compression is, therefore, quite efficient in transferring the compressive stress in this portion. The tensile stress is entirely taken by the mild steel plate at the bottom in conjunction with the bolts.

Another method of forming a joint in such members is illustrated in Fig. 434. In this joint the lower side is indented so as not to depend wholly on the strap and the bolts.

(2) *Bearing Joints* : The following type of bearing joints are commonly used :

(i) *Halving* : This joint is used for connecting two timbers crossing or meeting each other in such a way that the pieces are made flush at top by cutting a piece off the end of each across their entire width and to half their depth. Halving may be ordinary, as in Figs. 435, 436, bevelled, as in Fig. 437, or dovetailed as in Fig. 438. Wall-plates on top of two walls adjacent and at right angles to each other are joined at the end where they meet either by an ordinary or bevelled halved joint, and the collar in a collar beam truss is joined to the principals by a dovetailed halved joint. (See Fig. 581).

(ii) *Notching* : This joint is shown in Figs. 439 to 441 which show an isometric view of a single notch, its section, and an isometric view of a double notch respectively. Joists are notched and nailed to wall-plates. The shoulders help keep the joints in position.

(iii) *Cogging* : This joint is shown isometrically, as well as in section in Figs. 442, 443 respectively. The tie-beams of trusses are sometimes cogged on to wall-plates; or when wall-plates, purlins, or rafters have timbers crossing them, and when

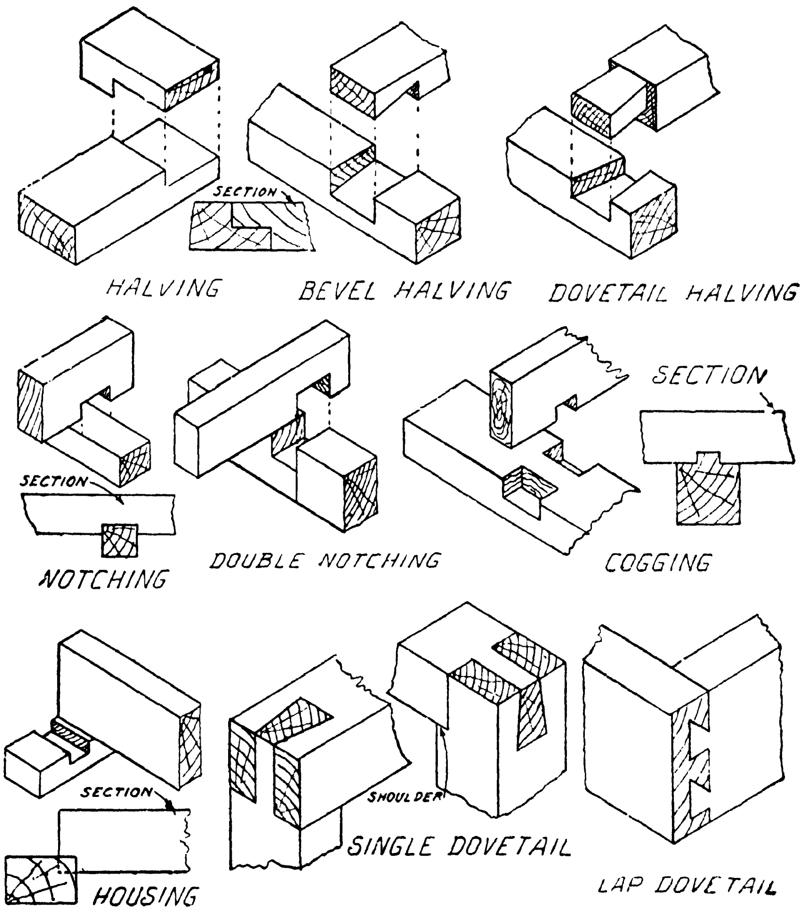
the entire depth of the bearing timber is required for strength, cogging is resorted to.

Figs. 435. 436. 437. 438.

Fig. 439 to 443.

Figs. 444.

Fig. 445.



Figs. 446. 447. 448.

Figs. 435—448: Bearing joints.

(iv) *Housing* : When the entire thickness of a piece of timber fits into a notch in another, a housed joint is formed. The ends of treads and risers of a stair are housed in a string. (See Fig. 394, page 185.) Fig. 444 shows an isometric view of a housed joint, and Fig. 445 shows a housed joint in section

between a bridging joist and a wall-plate where the full thickness of the bridging joist is required for resisting the shear at ends.

(v) *Dovetailing* : These joints are effected by cutting wedge-shaped alternate pieces out of each timber and fitting the projections of the one into the notches cut into the other—used for curbs of skylights, corners of boxes, drawers, cisterns, etc., where the depth is sufficient for such a joint. Figs. 446, 447 show single common dovetails, and Fig. 448, lap dovetail. In the latter the joint is seen on one face and the other face is quite clear.

(vi) *Mortise and Tenon:* This joint is effected by cutting a projection called a tenon in one piece, which fits into a corresponding hole or mortise in another. The pieces are held together and the joint further strengthened by driving wedges from the back or by dowel pins from the face, or by both. Fig. 450 shows an isometric view of the mortise and tenon separately and Fig. 449, a wedge. This joint is very common and occurs most frequently in woodwork.

(vii) *Joggle, Stub, or Stump Tenon* : This is similar to above, but the tenon is short, fitting into the corresponding sinking, and does not extend throughout the thickness of the mortised piece. It is commonly used at the foot of a post to prevent it from sliding away from the sill (Fig. 451).

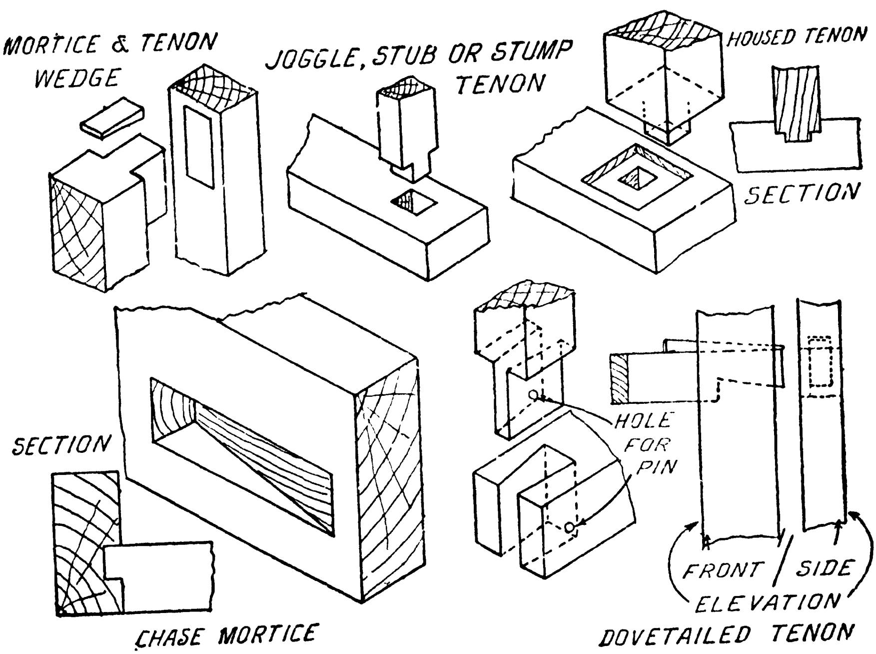
(viii) *Tenon and Housed Joint* : When the ordinary tenon described in (vi) above is insufficient to develop the necessary bearing strength, the whole end of one post is let bodily or housed into the sinking cut to a depth of about 12 mm. (½ in.) or so in the other and further tenoned into the corresponding mortise below, as shown isometrically in Fig. 452. The key, or the small tenon, provided in the joint helps abutting the shoulders close together. Fig. 453 shows a section of the joint.

(ix) *Chase Mortise* : This joint is made when subsidiary timbers are to be fixed between main timbers already laid in position and so are immovable, e.g., fitting ceiling joists between binders, etc. It is illustrated in Figs. 454, 455.

(x) *Dovetailed Tenon* : This is shown in Figs. 456 to 458 in front and side elevations. The tenon is formed of dovetail shape on the end of one piece, and the mortise is cut into another,

long enough to pass the wider edge. A hardwood key or wedge, driven as shown, makes a tight joint and keeps the pieces together. This type of joint is used when the pieces are to be connected and taken apart occasionally.

Figs. 449. 450. 451. 452. 453.

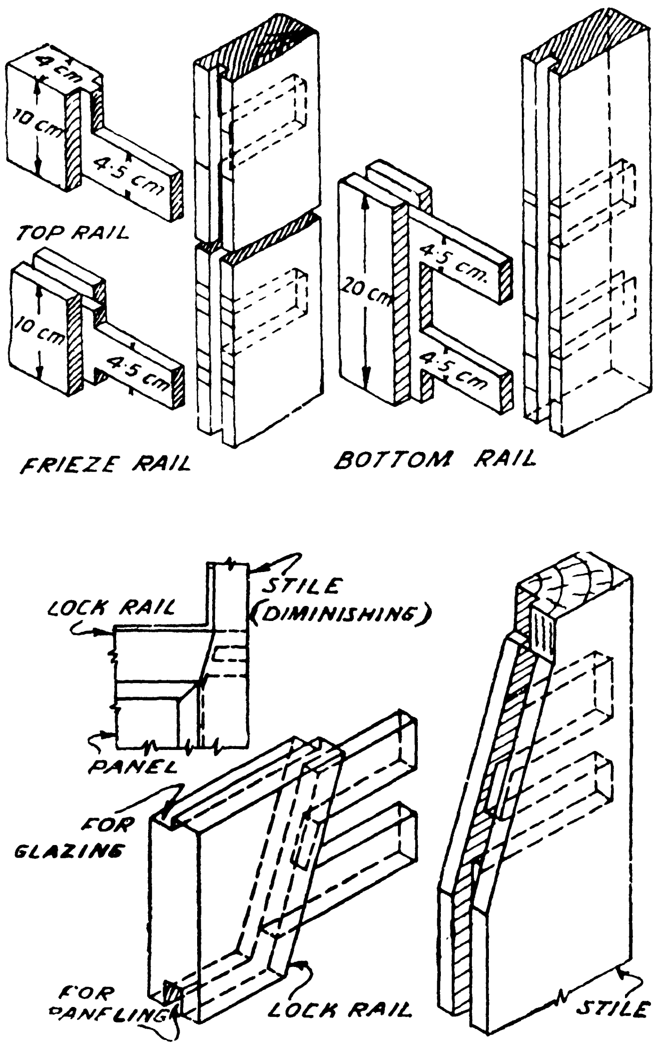


Figs. 454. 455. 456. 457. 458.

Figs. 449—458.

(xi) *Tusk Tenon* : This joint is specially suited for framing of floor timbers of equal depth meeting each other at right angles. (See Figs. 522, 523.) It is also used for framing binders into wooden girders in the case of framed floors. (See Fig. 531.) It causes the minimum loss of strength and yet holds the pieces securely together.

(3) **Framing Joints** : These are used in frames of doors, windows and partitions. These joints are similar to the bearing joints described above, but slightly modified to meet the special requirements, the primary consideration being not strength, as in bearing joints, but endurance.



Figs. 459 to 463:

Showing the joints used in door shutters. Fig. 459 is between the top rail and stile; 460 between bar or frieze rail and stile, and 461 between lock rail and stile. Fig. 462 is between a diminishing stile and lock rail, of which 463 is an elevation. (See also Fig. 303, page 151.)

A frame is made by joining together narrow pieces of timber usually not exceeding 8 cm. (3 in.) in width and 5 cm. (2 in.) in thickness, by a mortise and tenon joint, to enclose a number of rectangular or other shaped spaces. These spaces are filled by boards called panels, the edges of which are fitted into grooves made inside the edges of the narrow bordering pieces.

The joints which consist of widening or side joints, angle or corner joints, and frame joints are not required to resist great stresses, but must be so made that they will not be affected by atmospheric influences which cause the wood, even though well-seasoned, to warp, split, expand, or shrink, and consequently, to look unsightly and soon deteriorate.

The precautions necessary to prevent this are :

The work must be so framed that the minimum surface of end grain should be exposed. The thickness of the boards or the panels should be sufficient to prevent warping.

The joints should be so made as to allow for freedom of shrinkage and expansion.

The fixed parts used in the work should be made as narrow as possible, increasing the number of parallel joints so that the shrinkage is distributed over many joints and is not appreciable at any one place.

As sapwood is more liable to shrink and also more subject to decay, only well-seasoned and treated timber from heartwood should be used.

Prevention of Warping : To prevent warping, one of the following devices should be adopted :

(a) Two single small tenons, one above the other, will prevent the tendency of a wide rail in panelling to twist or split. (Fig. 462).

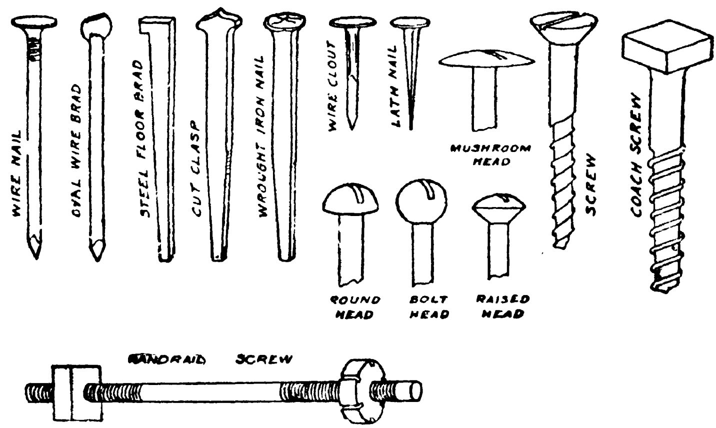
(b) Holes should be drilled through the edges to the boards to be jointed for making a wide panel, and iron dowels inserted in them. This would make them stiff against warping.

(c) Battens should be fixed at right angles to the boards on the back side by means of screws fixed in slots in the battens. The screw fixes the batten and board together, but allows suffi-

cient freedom for the boards to expand or contract, and the battens stiffen the boards against warping.

This arrangement is usually adopted in the case of large drawing boards, on the backside.

The side joints, or what are called *widening joints,* may take the form of either a butt and chamfer which makes a V-joint or a butt and bead which are called *matched joints,* and the process, *match boarding.* Other varieties of widening joints are tongued and grooved, rebated, ploughed and tongued, rebated and filleted, etc., which have later been explained with illustrations in Figs. 526 to 533. The angle joints are either plain mitre, or other varieties of mitred joints. (See Figs. 416 to 419).



Figs. 464—477.

Fastenings: Fastenings consist of the following:

(1) Pins, which may be either of wood (called *tree-nails*); cast or wrought iron nails; brads, clasps, spikes, or clouts, or screws and bolts.

(2) Hard wood wedges or tapering keys.

(3) Wrought iron straps.

(4) Sockets and shoes.

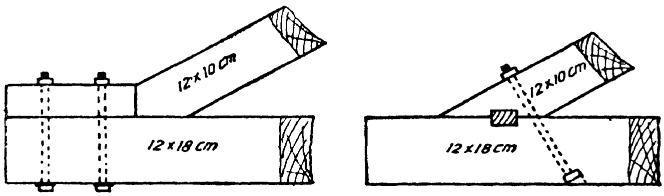
Brads are tapering nails with heads projecting only on one side.

Clasps are flat nails cut from wrought iron or steel plates about 8 cm. (3 in.) or less in length.

Spikes are similar to clasps, but 8 to 15 cm. (3 to 6 in.) in length.

Clouts are nails with large, flat, circular heads.

Coach Screws are used for securing iron plates to timbers, or timber to timber. They have wide threads, as in a wood screw, and square heads.



Figs. 478, 479:
Oblique-shouldered joints.

Dogs are pieces of flat or round wrought iron, bent at the ends. The bent heads are hammered into wood to draw the timbers butting against each other together to strengthen the joints as in shoring, staging, gantries. (See Fig. 265, page 131.)

Hand-rail Screws are inserted to strengthen the bends for hand-rails at the change of direction of the stair.

Most of the above fastenings are illustrated in Figs. 464 to 477.

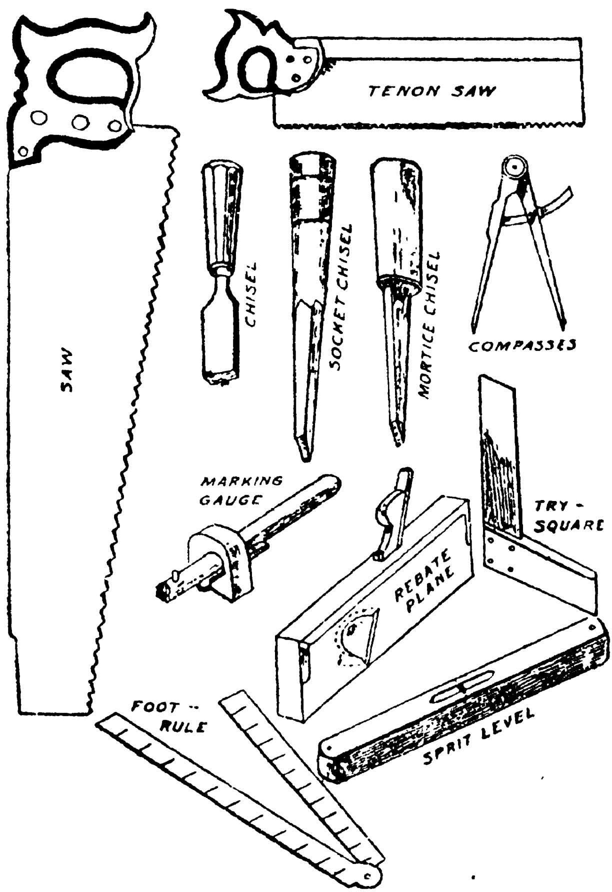
Wrought Iron Straps are used on roof trusses to keep the timbers in the required position, and are fixed by bolts.

Sockets and Shoes are usually of cast iron used on ends of timbers to protect the ends from splitting, as on wooden piles. (See Figs. 26, 27, page 27).

(4) *Oblique-shouldered Joints* : These joints occur when the members of a frame-work meet at an acute or obtuse angle; e.g., a principal rafter and a tie-beam, a king-post and struts, etc. These are effected in several ways, but the single abutment and tenon joint in king and queen post trusses, explained and illustrated in Fig. 581, is as common as it is simple and effective. It is usually further strengthened by means of w. i. straps.

Two other methods are illustrated in Figs. 478 and 479. In Fig. 478 a wooden piece is bolted on the top of the tie-beam to

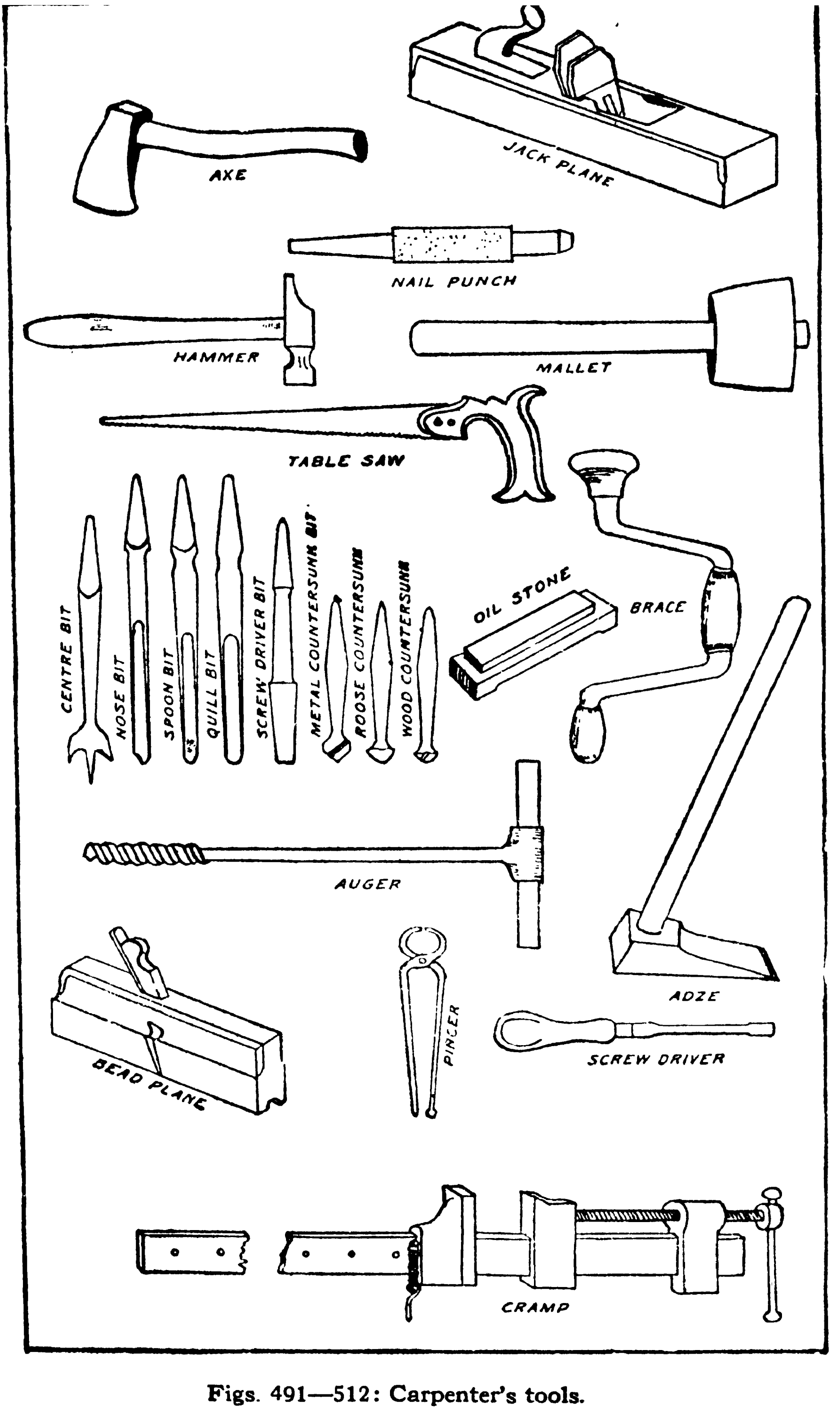
serve as a cleat against which the inclined strut abuts. In Fig. 479 notches are cut on the top of the tie-beam and bottom of the rafter, and a hard-wood cog is driven. A heel strap further strengthens the joint.



Figs. 480—490:

Carpenter's tools.

The tools used in carpentry are illustrated in Figs. 491 to 512.



Figs. 491—512: Carpenter's tools.

Questions for Revision on Chapter 10

(1) Explain the following terms: (a) Newel, (b) Curtail step, (c) Quarter space landing, (d) Open newel stair, (e) Housed string.
(2) What are the thumb rules giving a relation between a tread and a riser?
(3) What should be the minimum head room and where is it measured?
(4) Design a dog-legged staircase 1 m. (3 feet) wide, for a height of 3 m. (10′–6″) between tops of successive floors. A clear headway of 2 m. (6′–6″) is required below the landing.
(5) Show in a cross section any one method of jointing a riser to a tread of a wooden stair.

Questions for Revision on Chapter 11

(1) What is a flitch beam, and where is it used?
(2) What are the general principles in designing joints in structural woodwork for the proper transmission of the stresses to which the member may be subjected?
(3) Give a sketch of a simple lengthening joint to resist (a) Tension and (b) Compression.
(4) What is a bearing joint? Name three types of bearing joints.
(5) What precautions are taken to prevent warping of wood of thin section?
(6) How is an oblique-shouldered joint strengthened? Show by means of a sketch.

PAVING ON GROUND FLOOR : 12

THE types of flooring commonly used for the ground floor are given below :

(1) *Muram* flooring.
(2) Brick on edge flooring.
(3) Cement concrete flooring.
(4) Flagstone flooring.
(5) Tiled floors.
(6) Asphalt floors.
(7) Terrazzo floors.
(8) China mosaic floors.
(9) Timber floors.

These are described in detail in serial order:

(1) Muram Floor : In rural districts of India, *muram* (disintegrated rock) or mud floors are very common. They are made with scrupulous care and are usually maintained in excellent condition. These floors are cheap, èasily made and repaired, and last sufficiently long for the purpose. They further maintain an equable temperature both in the winter and summer, and are very satisfactory for Indian conditions, particularly in the homes of those who move bare-footed in the house. The only drawbacks of this type of flooring are that in order to maintain the flooring in good condition, an occasional wash of cow-dung has to be given, which is objectionable from the sanitary point of view, and also that this flooring is to a certain extent absorbent; but in these respects the flooring can be improved if it is properly made and maintained.

The sub-grade should be made of hand-packed rubble, or broken hard brick, about 25 cm. (9″) thick, wetted and well-rammed. Above this should be spread a 15 cm. (6-inch) layer of *muram,* with coarser pieces at bottom and finer at the top. On the top of this a layer of powdery or flaky variety of *muram,*

about 25 mm. (1″) thick, should be spread. Water should be freely sprinkled on it and the surface rammed well. After this, copious water should be sprinkled again until the floor is fully saturated with water and a thin film of about 6 mm. (¼″) of water is formed on the top. The surface should be trampled under the feet of workmen and levelled until the cream of *muram* rises to the top. It should then be left to itself for 12 hours, and then rammed both in the morning and in the evening for three days by means of wooden flat rasps provided with a handle. After this, the surface should be smeared with a thick paste of cow-dung and the floor rammed for two days in the morning. If it is summer time it will, by now, be sufficiently dry to receive the final thin coat of a mixture of 4 parts of cow-dung and 1 of cement applied evenly and wiped clean immediately by hand. The floor made in this way is very smooth, hard, and fairly impervious to water.

Once in a week or two, according to the traffic on the floor, the surface should be given a thin wash of cow-dung and cement and wiped clean immediately to maintain the surface in a good condition. If a thicker coat is applied, it would soon cake and peel off.

In places where *muram* or laterite is not available, a floor of mud can be made equally well. The difference between a *muram* and mud floor lies in the quantity of water. Whereas water is used very freely in the preparation of a *muram* floor, it should be very sparingly used in a mud floor. If the earth, as it comes fresh from a pit, is moist, there is no need of adding any water to it at all. A layer of about 9 inches of soil below the ground surface should be thrown out, and the earth below it should be used for making the floor. If the surface of the ground, from which the earth is obtained, shows cracks, the earth should be mixed with sand. The exact quantity will depend upon the clayey or sticky nature of the earth. A layer of 25 cm. (9 inches) of loose, moist earth should be evenly spread and reduced to about 15 cm. (6 inch) thickness by ramming. The final treatment with cow-dung and cement is the same as in the *muram* floor.

(2) **Brick Floors :** Brick flooring is very common in alluvial tracts like the Uttar Pradesh, the Punjab, and Sind, where

stone is rare, and good, hard, well-burnt bricks are readily available. It is suitable for stores and godowns, etc., where heavy articles are put. The only drawback of this type of flooring is that it is absorbent.

The sub-grade should be made with a 25 cm. (9 in.) layer of rubble, brickbats, and 10 to 15 cm. (4 to 6 in.) thick layer of lime concrete on its top. Over this, bricks of the best quality should be laid either flat, or preferably, on edge, the sides being rubbed, if necessary, to give fine joints about 1.5 mm. (1/16th in.) thick. Care should be taken to see that the masons cover the sides of the brick last laid with mortar before placing the next brick against it. In no case should the joints be filled by pouring cement or mortar grout from the top; covering the top with mortar should not be allowed, as it is likely to be used to conceal bad workmanship. The bricks may be laid with rows having joints parallel and at right angles to the walls or in herring-bone pattern. (See Fig. 199, page 99).

(3) **Cement Concrete Flooring** (Indian Patent Stone): Floors of cement concrete 2.5 to 4 cm. (1 to 1½″) thick laid on a 10 to 15 cm. (4 to 6″) bed of lime concrete, have now become very common, especially in hospitals, kitchens, bathrooms, wash-houses, etc. If proper attention to details is given, this makes an excellent, non-absorbent, smooth, and durable floor. It is even cheaper than ordinary flagstone flooring and possesses all the advantages of the costlier types. However, if it is carelessly made, it is a perpetual source of trouble, because it can never be satisfactorily repaired by patch work.

The sub-grade is made as usual by laying a 10 to 15 cm. (4″ to 6″) layer of lime concrete on a firm bedding of rubble. The surface of lime concrete is given the necessary slope to facilitate the washing down of the finished floor; usually for inside floors, a slope of 12 mm. in 3 m. (½″ in 10 feet) is sufficient. The lime concrete layer should be watered and well rammed for two days, and on the third day the wearing coat of cement concrete should be laid as described below :

The proportion of cement concrete should be 1 part of cement to 2½ parts of coarse sand to 3½ parts of crushed stone, 12 mm. (½ in.) size. The materials should preferably be taken on the basis of one cement bag as a unit (1 bag = 50 kg. = 1.25

c. ft.). The concrete should be mixed on an impervious platform with sufficiency of water. Workmen are interested in using a larger quantity of water because it makes the mixing easy, but this should not be permitted, as it considerably reduces the strength and wearing properties of concrete. With dry aggregate, about 18 to 22.5 lit. (4½ to 5 gallons) of water per bag mix is sufficient.

The area to be concreted should be divided into suitable sections, each not measuring more than 1.25 m. × 1.25 m. (4 feet by 4 feet), and then battens of the width equal to the thickness of the cement concrete and 6 mm. (¼ in.) thick should be laid on edge on the concrete bed along the sides of the sections. The top of the battens should be correctly adjusted to the required level of the finished flooring.

The top of the sub-grade should be thoroughly wetted, but no pools of water should be allowed to stand. Just a little dry cement should be sprinkled over a small area, and this should be swept with a broom and immediately a layer of concrete should be evenly spread on the sub-grade. As this is being done by one mason, the portion on which concrete has already been spread should be beaten by wooden beaters. The quantity of water in the concrete being small, the surface at first appears to be rough, but as tamping continues, the mortar creams to the surface, which can now be finished smooth by means of wooden trowels. Masons are in the habit of sprinkling dry cement on the surface so as to obtain a good finish with less labour. This must never be permitted, as the dry cement forms hair cracks and scales which chip off in due course.

The adjoining tiles should be completed on different days.

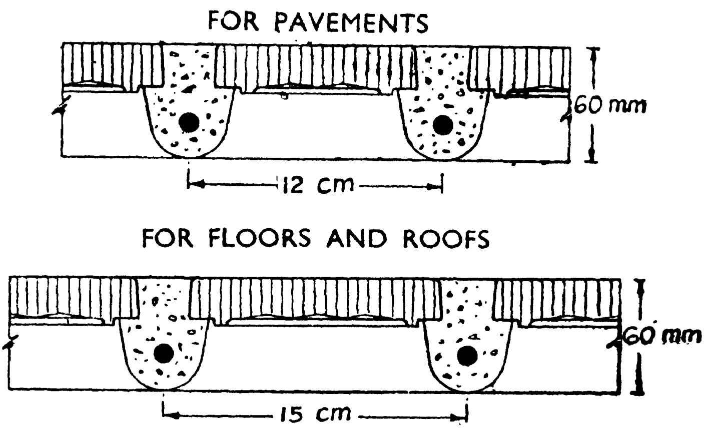
After the flooring is completed, the surface should be covered with 25 mm. (1″) of wet sand and kept wet for 10 days by sprinkling water at suitable intervals.

(4) **Stone Paved Floors** : These floors consist of a firm sub-grade of rubble packing and 10 to 15 cm. (4 to 6 in.) of lime concrete on which stone slabs, of the required thickness, are laid in lime mortar. The stone paving may be of 8 to 10 cm. (3″ to 4″) thick Blue Basalt, 6 cm. (2½″) thick Porebunder lime stone, or 2.5 to 4 cm. (1″ to 1½″) thick Shahabad or similar flagstone, either rough or polished.

The stone should be of rectangular size, square or oblong, and should have the edges squared.

Two stone slabs are first laid in two diagonally opposite corners on a layer of mortar about 2 to 3 cm. (¾″ to 1″) thick, and the levels of the two stones are so adjusted as to give the required gradient for facilitating the washing of the floor. A string is stretched tight from the top of one slab to that of the other, and all intermediate slabs are then laid so that their top just touches the string. Each slab is firmly and evenly bedded on stiff mortar and lightly tapped with a wooden mallet. If the slab requires to be raised, the use of stone chips for packing should not be resorted to, but stiff mortar only should be used.

When all the slabs are laid, the mortar in the joints is raked out for a depth of about 2 to 3 cm. (1 in.), and the joints are flush pointed with cement mortar (1:3).



Figs. 513, 514:
Reinforced glass pavements.

In superior quality work, polished stone slabs dressed square on all sides to the full depth are used, and the flooring is laid in some pattern to add an architectural effect.

Pavement Lights : Pavement light frames are of various types, fitted with pressed glass blocks for transmitting light downwards. When it is desired to direct the light farther back into a room or to one side, one of the forms of prismatic glazing is adopted. The semi-prisms formed on the underside collect light

and project it in the desired direction. They are suitable both for pavements, and flat or sloping roofs.

A variety of these is the *Glas-crete* pavement light manufactured by Messrs. King & Co. of England. Figs. 513, 514 show cross sections of *Glas-crete* pavements, and Fig. 515 a *Glas-crete* board which can be fixed either in a pavement or a roof.

(5) **Tiled Floors** : Tiles, either of pottery or cement concrete, are either square or hexagonal and are manufactured

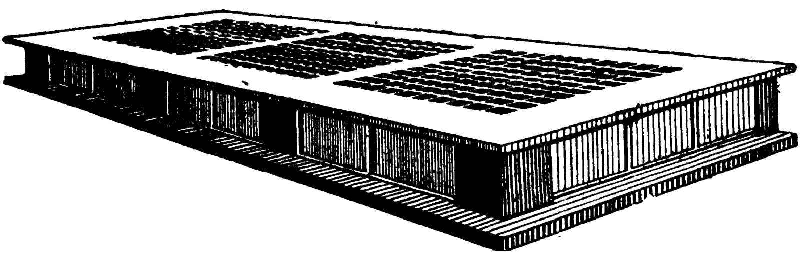


Fig. 515:
Photographic view of glass pavement.

in different colours and designs. The method of laying a tiled floor is somewhat similar to that used for laying a stone pavement, but more care and skill are required in the execution of this type of flooring.

On the sub-grade, a thin layer of mortar of cement and very fine sand (1 : 1) is spread evenly, and the tiles are truly and evenly set in a thin paste of cement applied on the sides. The joints in this flooring are thin (as thin as paper.) The extra cement that oozes out through the joints to the surface is immediately wiped clean with sawdust.

After 2 or 3 days the joints are first rubbed with a carborundum stone, so that slight projections or edges rising above the surface are levelled. The whole surface is then polished, by hand or machine, first with a softer variety of carborundum stone, and then with a pumice stone. Finally the surface is washed with a weak solution of soft soap in warm water.

(6) **Asphalt Flooring** : Asphalt, on account of its black colour and bad smell, particularly in the initial stage, has been regarded as suitable only for outdoor paving and road surfac-

ing. However, with various improvements in its manufacture and use, and notably with the introduction of colour, it is becoming more and more popular for indoor flooring also. Asphalt floors are extremely water-tight, non-slippery, dustless, and noiseless. The plastic nature of asphalt makes it a very suitable material for use on terraced roofs, because it conforms to slight movements due to expansion and contraction caused by variation in temperature.

Preparation of Mastic Asphalt : The solid asphalt sold in drums is broken into pieces and put into an iron pot which is heated from below. It is stirred well while it melts, and when thoroughly fused, clean, coarse grit or broken stone is mixed with it in the proportion of 2 to 1. The mixture is continually stirred until light brown smoke is given out, and the mixture is sufficiently thin so as to drop freely from the stirring rod. The pot should then be taken off the fire, and the *compost* should be used as quickly as possible.

Laying the Compost : In ordinary cases, one layer 12 to 25 mm. (½ to 1 in.) thick is sufficient; but where infiltration of moisture under pressure is expected, e.g., in basement floors or water cisterns, it is advisable to spread the mastic in two layers, breaking joint. Similarly, where coloured asphalt is used, two layers are necessary. The lower layer is of ordinary asphalt and the top one is of coloured asphalt.

The compost, or mastic, hot from the cauldron, is spread on a previously prepared base of concrete by means of masons' trowels, in a layer of even thickness. It is immediately screeded and trowelled, so as to give a uniform level surface. Before the compost becomes hard, a small quantity of very fine sand is sifted over the surface and well rubbed into it with a trowel.

It is important that the day's work is not stopped with a vertical joint, but an overlap of an inch or two is made, as shown in Fig. 517. Similarly, corners and edges at ends should be rounded off by carrying a layer 5 to 8 cm. (2 or 3 in.) vertically against the wall flush with the plaster. (See Fig. 518.)

(7) Terrazzo Flooring : This is a special type of concrete flooring which is becoming more and more popular on account of its highly decorative effect.

The top of the unsinkable base slab is kept about 4 cm. (1½ in.) below the level of finished flooring. On the top of the base, a layer of fine sand 6 mm. (¼ in.) thick is spread to act as cushioning, and this is covered with a specially made tar paper obtainable in the market. On the top of the tar paper is spread

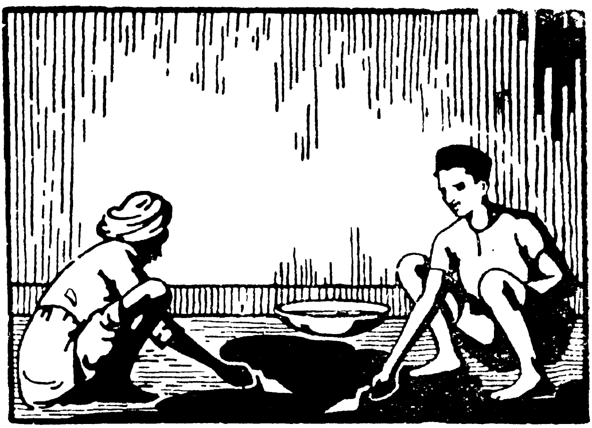
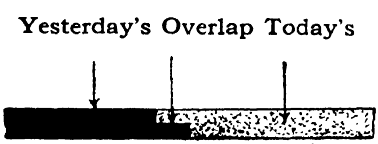
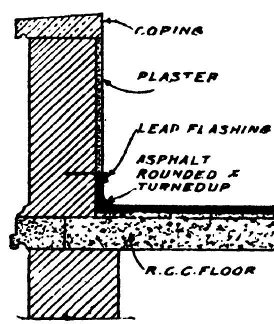


Fig. 516:
Laying Asphalt Compost.





Figs. 517, 518.

a mixture of one part of cement to three parts of sand, with about 27 lit. (6 gallons) of water per bag of cement. This layer is about 25 mm. (1″) thick. While this layer is being laid, brass or aluminium dividing strips, 4 cm. (1½″) in width and 1.25 mm. (20 gauge) in thickness, are placed on edge to conform to the pattern previously designed. When the lower layer has sufficiently hardened, the terrazzo mixture, consisting of one part

of coloured cement to three parts of marble chips and not more than 20 lit. (4½ gallons) of water per bag of cement, is laid just up to the top of the brass strips, and the surface is rolled both lengthwise and crosswise. As rolling proceeds, additional chips are spread on the surface, if found necessary, so that 85 per cent of the finished surface shows stone chips. Immediately after rolling, the surface is floated and trowelled. Different patterns are executed with cement of different colours.

The terrazzo mixture should be rather stiff, as with a thin mix the stone chips are likely to get loose in course of time. If the mixture made with the quantity of water already specified is not workable, the proportions of cement and chips should be varied to obtain the proper consistency, but in no case should the quantity of water be increased.

The finished surface is then kept covered under 3 cm. (1″) layer of wet sand for 7 days.

When the terrazzo concrete has sufficiently hardened so as to prevent any dislodgment of the stone chips, the surface is polished with a grinding machine fitted with carborundum grinding stones. During the process of grinding, the surface is kept wet. Any holes, caused either by air bubbles or by the dislodgment of the particles of grit, are filled with a thin grout of coloured cement paste, and the surface is kept moist for another week. After this period the surface is lightly ground once more to give a fine polish.

Finally the surface is washed with warm water and soft soap, and wiped dry.

Note : The cushioning layer of 6 mm. (¼″) fine sand and the tar paper prevent any small movement in the sub-grade from affecting the terrazzo top.

In a variety of this type of flooring called "mosaic flooring" pre-cast cement tiles with marble chips laid on a surface of coloured background, moderately polished are laid as described in (5) above and polished with a portable machine when firmly set.

(8) **China Mosaic Tile Floor** : A firm base of concrete is prepared with the necessary fall in the proper direction. On the top of this, lime mortar about 12 to 18 mm. (½″ to ¾″)

thick is laid on a small portion, which can be finished with the laying of tiles in 3 or 4 hours. Lime mortar, if laid on a large area, will get dry and hard before the pieces of tiles are set. On the bed of lime mortar, a layer of neat, dry cement about 2.5 mm. (1/10th of an in.) thick is sifted and pieces of broken tiles (either china glazed or of mosaic cement) are arranged in such designs and colours as may be desired.

The breaking of tiles in the proper way is very important. The tiles should be broken to the shape of a wedge, with the glazed or polished side on the broad face.

When the pieces are arranged in a small portion in the necessary pattern, dry cement is sprinkled on the top, and either a light roller is slowly passed over it or a long flat piece of wood is placed over the surface and lightly hammered on top. Thus the pieces are firmly set in mortar without even slightly disturbing the pattern. This is done for an hour or so and then the extra cement is wiped clean with sawdust.

(9) **Timber Floors:** Timber floors are not so common for the ground floor in this country, as the height of the plinth above the ground level gives sufficient protection from damp, but they are eminently suited for buildings on hill-stations or in localities where the climate is damp or cold.

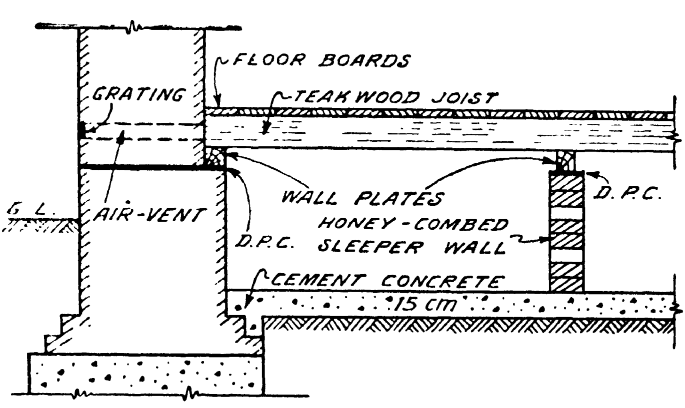


Fig. 519:
Timber flooring on ground floor.

Timber floors consist of boarding supported on timber joists, which are nailed to wall-plates. In the case of large rooms where the distance between the walls is considerable, intermediate

dwarf walls are constructed to support the joists. These walls are termed *dwarf-walls* or *sleeper-walls*. A longitudinal piece of timber is fixed on the top of the sleeper wall and the timber joists are nailed to this piece.

In order to stop the damp from rising, a 15 cm. (6″) layer of concrete is placed all over the bed, and damp-proof courses are inserted throughout the width of the wall immediately below the wall-plate. This is called oversite concrete and is a weak mix.

The hollow space between the flooring and the concrete is properly ventilated by keeping openings in the main wall above ground level. These openings are fitted with wire netting to prevent rats and birds from getting access to the cavity below the flooring.

Fig. 519 shows the details of a timber floor. For such floors, the plinth need not be high; just 20 to 30 cm. (9 in. or a foot) is sufficient.

Questions for Revision

(1) Describe in detail the process of making a cement concrete floor often called Indian Patent Stone.
(2) How is a muram floor made, and what is the difference in the technique of a muram and mud floor?
(3) How is mastic asphalt prepared and laid for flooring? Where is it most useful?
(4) What is a terrazzo floor and how is it made?

CONSTRUCTION OF UPPER FLOORS : 13

THE systems of upper floors may be classified according to the supporting beams and the principal material going into the composition of the floors.

1. Wooden floors:
   (a) Single.
   (b) Double.
   (c) Framed.
2. Steel Girders and Wooden Joists.
3. Steel Joists and Flagstones, or Concrete.
4. Steel Joists and Jack Arches of Brick or Concrete.
5. Steel Girders and R.C.C. Slabs.
6. Steel Girders and Pre-cast R.C.C. Units of Self-centering Reinforcing Materials.
7. Reinforced Concrete Floors.

The development of the modern floor may be traced as follows: The time-honoured wooden floors were not deemed satisfactory, firstly, because the spans were necessarily restricted, and with increased spans the cost soared disproportionately high. Secondly, they were not sufficiently fire-resisting. With the advent of rolled steel beams as a cheap structural material, the wooden beams were replaced by steel beams, and a combination of steel beams and wooden joists was very much in vogue for some time. With the introduction of steel frame construction, fire-resisting floors were very much in demand and, as a consequence, steel joists and brick or concrete jack arches captured the field. With the advent of R.C.C. construction, however, these also fell into the background, as R.C.C. floors afford comparatively flat ceiling instead of the curved surfaces of the arches. But the trouble with R.C.C. floors was that the temporary sup-

ports in the form of centering, required during the time of construction and the period of setting of the concrete, unnecessarily enhanced the cost. This gave rise to various methods of construct-

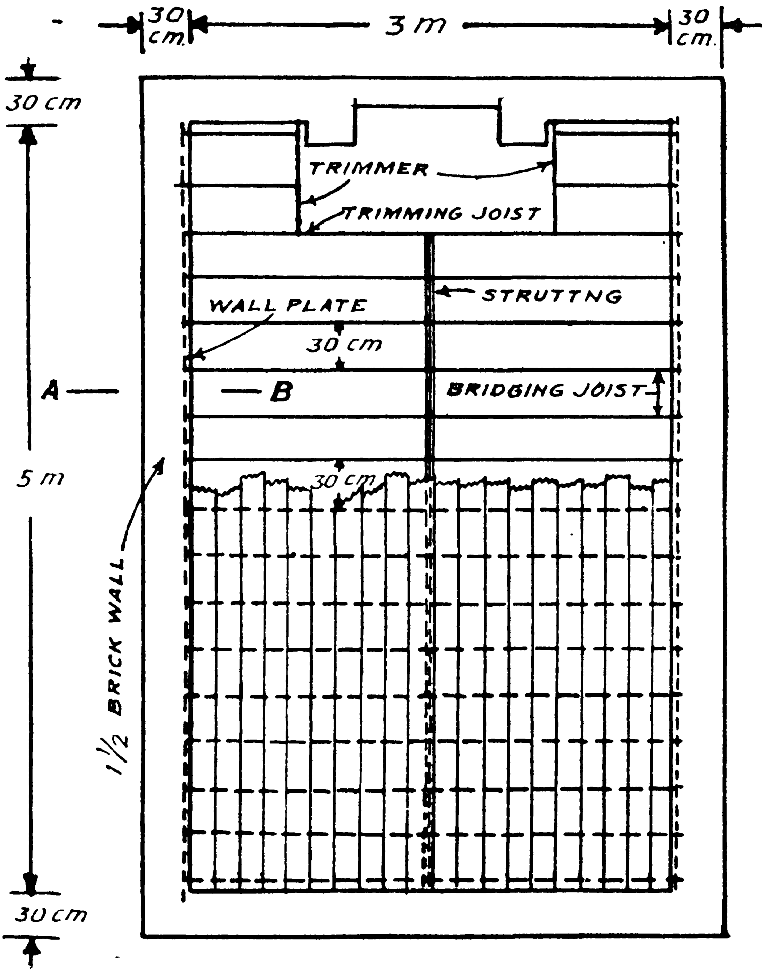


Fig. 520:

Plan of a single wooden floor showing trimmers and trimming joist to accommodate a fire-place.

ing fire-resisting floors with either precast R.C.C. light units or self-centering reinforcing fabric which eliminated the centering altogether.

At present, purely timber floors are seldom constructed in this country. In domestic buildings they are sometimes constructed in combination with steel beams; but the general tendency is to use one of the forms of fire-resisting floors.

(1) **Timber Floors:** A timber floor is light, but is neither sufficiently fire-resisting nor sufficiently sound-proof, but these two defects can be remedied to a certain extent by some special treatment. Besides these two disadvantages, this flooring is more costly than other types, and nowadays it is used very little.

The supporting system of these floors, where the room is large, consists of timber joists called *bridging joists* resting on sub-beams, called *binders,* which in their turn, are supported by main beams called *girders.*. If the size of the room is small, the girders, or both the girders and binders, may be dispensed with.

Flooring consisting of bridging joists as the only supporting members, is called a *single floor,* that consisting of bridging joists and binders is known as *double floor* and the one with bridging joists, binders, and girders is termed as a *framed floor.*

(a) *Single Floor:* These floors are made by nailing wooden boarding about 30 mm. ($1\frac{1}{4}''$) thick on bridging joists which are spaced at 30 to 40 cm. (12″ to 16″) c/c. The bridging joists are nailed to timber wall-plates fixed in the wall. The joists should not only be strong enough to bear the load, but must be sufficiently stiff so that the floor does not deflect under the loads. The limiting span of this type of floor is 3·75 m. (12 feet). The size of joists should be calculated on the basis of the total load supported and the span. A thumb rule for finding the depth of the bridging joists is,

$$\text{depth} = (4 \times \text{span in meters} + 5) \text{ cm.}$$

e.g. span 2·5 m., depth of joists $= 4 \times 2{\cdot}5 + 5 = 15$ cm.

$$\text{depth} = \left(\frac{\text{span in ft.}}{2} + 2\right) \text{inches}$$

e.g., span 8′, depth of joists $= \left(\frac{8}{2} + 2\right) = 6''$.

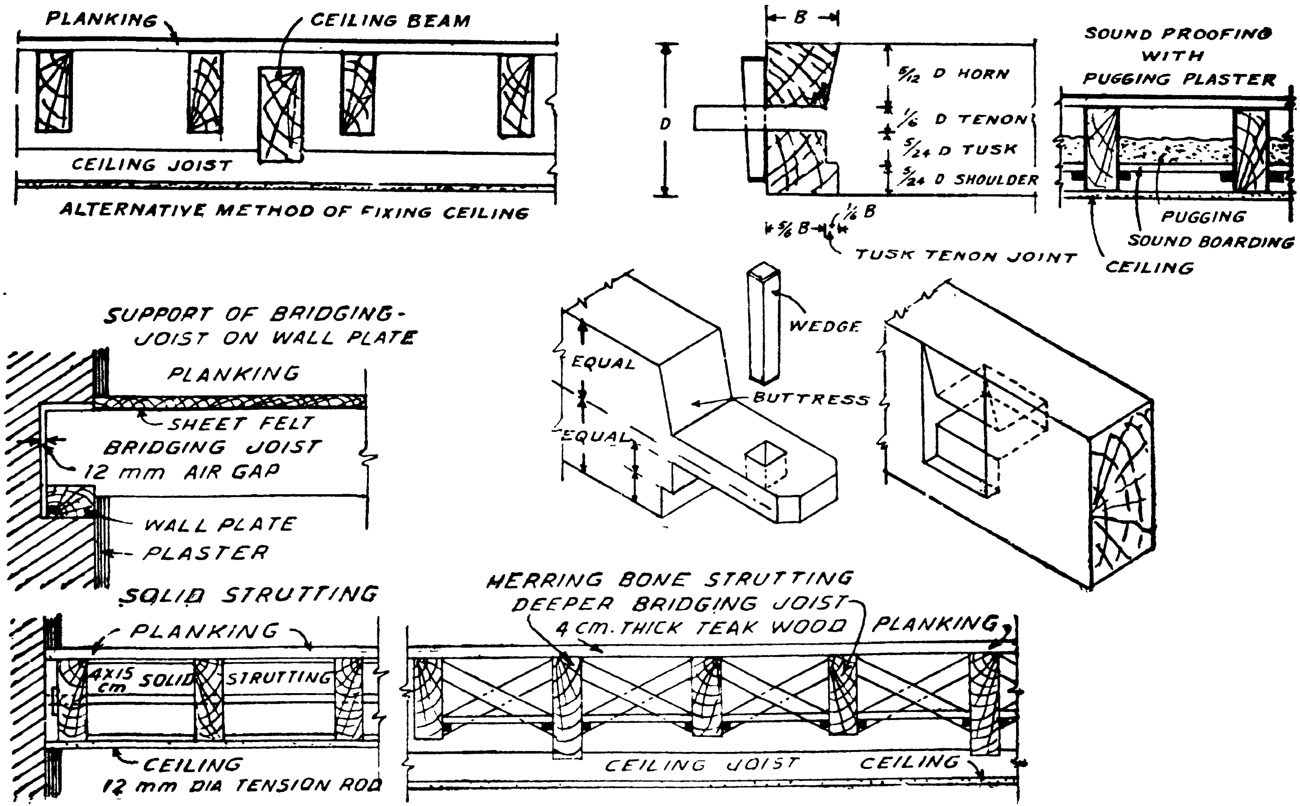
The width of the joist is from 5 to 8 cm. (2″ to 3″).

When the span of the joist is longer than 2·5 m. (8 feet), the joists tend to buckle sideways and require to be strutted apart. Strutting may be done in either of two ways. One is known as herring bone strutting and the other is known as solid strutting.

Figs. 521-523.

Figs. 524-527.

Figs. 528, 529.



Figs. 521—529: Details of single floor.

Herring-bone strutting consists of small pieces of timber 5 to 8 cm. (2″ to 3″) wide and 2·5 cm. (1″) thick, inserted diagonally and crossing each other between the bridging joists. (See Fig. 529).

Solid strutting consists of pieces of timber boards about 1″ thick fixed at right angles to and between the joists and held tight by a tension rod passing through all the bridging joists and tightened at the ends. (See Fig. 528).

In a good class of work a 12 mm. (½″) teakwood ceiling is usually fixed to the underside of the floor. The methods used for fixing the ceiling are as follow:—(See Figs. 521, 522.)

(i) The ceiling boards are directly nailed to the underside of the bridging joists (Fig. 523). This method is the simplest and cheapest, but the flooring with this type of ceiling is not sufficiently sound-proof, without some special treatment and, besides, the ceiling is likely to crack or open at joints, due to vibrations.

(ii) In the second method, ceiling boards are nailed to ceiling joists fixed to every third or fourth bridging joist, which is made deeper than the rest. (Fig. 529). This method is costly and the flooring becomes thicker, but with the ceiling fixed in this way the floor becomes more sound-proof.

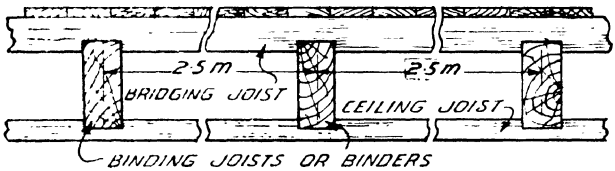
(iii) In the third method, separate ceiling beams and ceiling joists are used, and the ceiling is completely independent of the flooring (Fig. 521). This type of construction is much sound-proof, but is the costliest of the three.

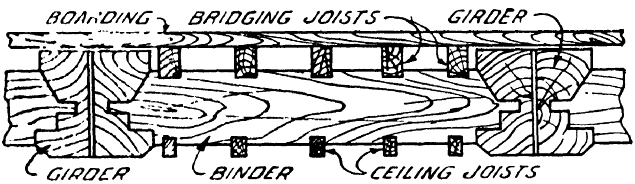
Where the ceiling is directly fixed to the bridging joists, special arrangements have to be made to render the floor sound-proof, such as using sound boarding and applying pugging plaster. Fig. 523 shows in detail the sound-proofing arrangement.

The only draw-back of this method of rendering the floor sound-proof is that the flooring is likely to rot, as the circulation of air is entirely prevented.

In general, compared to double or framed floors, single floors are cheaper and simpler in construction. The load being transmitted to the walls directly by bridging joists, the distribution of pressure is more uniform on the walls. But single floors, if used for large spans, sag and cause cracks in the ceiling below, if it is fixed to the bridging joists, special arrangements are neces-

sary to make it sound-proof. Single floors are economical up to a maximum span of 3·5 m. (12 ft.)





Figs. 530, 531:
Sections of double and framed floors.

(b) *Double Floors:* As already mentioned, when the span is too large for bridging joists, they have to be supported on intermediate beams known as binders. This type of construction is termed a double floor. Binders are usually spaced at a distance of 2 to 2·5 m. (6′ to 8′) c. to c., and rest on concrete or stone templates embedded in the wall. In fixing the position of the binder, it should be observed that, as far as possible, the binder does not come immediately above a window or door opening where the wall is weak. Binders should be so fixed in the wall that free circulation of air round their ends is not prevented. In short, the binder must not be embedded in the masonry of the wall. Fig. 530 shows a double floor with ceiling fixed to the underside.

Double floors are stiffer and more sound-proof than single floors, but the binders throw the load on the wall at a few points only, and thus the load of the floor is not uniformly distributed on the wall. The increased depth of the flooring also increases the cost of the building, and also reduces the head room.

(c) *Framed Floors:* (Fig. 531). With still greater increase in span, the size of binder, if used for spanning the whole distance, goes on increasing, and the cost of the floor also corres-

pondingly increases. It is then more convenient and economical to use a few beams to span the distance directly between the walls and to support the binders on these beams. The latter are of a heavier section and are termed girders. The spacing of girders depends on the limiting span of the binders, which is usually 4·6 m. (15 ft.)

If binders are supported on the top of the girders, the total depth of the floor increases, and to reduce this, it is usual to frame the binders into the girders by a tusk-tenon joint. (See Figs. 522, 531)

If the span of the girders is very large, and timber scantlings of the required size and length are not available, except at a prohibitive cost, mild steel beams can be used as girders.

Ends of binders in opposite directions should not be framed into the girder at one place, as this would weaken the girder. They should be staggered.

Design of Timber Floors: For this the bending moment is calculated in the usual way, assuming the member as simply supported. B.M. $= \frac{wl^2}{8}$. This is equated to fz, where $f =$ the working stress depending upon the kind and quality of timber used and $z =$ the modulus of section $= \frac{bd^2}{6}$ which also varies according to the kind of timber. Both these are given below in Table No. 15 for the common Indian timbers. In $\frac{bd^2}{6}$, d should be within the limits of $\frac{1}{18}$ to $\frac{1}{24}$ of the span and the ratio between b and d should be such that d should be between 1·5 and 3 times b.

Timber beams may be strong enough to resist the calculated bending moment and yet may deflect too much under load. They, therefore, require to be checked for deflection. The deflection normally allowed is $\frac{1}{360}$ of the span but when there is plastered ceiling below the floor, even this much deflection may cause cracks in it. In such cases it is limited to $\frac{1}{480}$ of the span. The general formula for deflection is $\delta = K \frac{Wl^3}{48E}$ where

TABLE No. 15*

WORKING STRESSES FOR FIRST GRADE INDIAN TIMBERS

Kind of Timber	Weight kg./m.^{3}	Tension parallel to grains kg./cm.^{2}	Compression parallel to grains kg./cm.^{2}	Shear parallel to grains kg./cm.^{2}	Modulus of Elasticity, E kg./cm.^{2}
Burma or Malabar Teak	660	150	125	8.8	113000
C. P. Teak	610	125	100	8.4	121000
Sal	865	150	105	12.3	135000
Chir	560	110	85	6.7	106000
Sain	850	150	120	10.9	113000
Deodar	520	90	85	11.2	95000
Jarrah	800	160	65	8.4	106000
Douglas Fir	500	110	85	7.0	120000
Kail	450	70	70	7.7	70000

K = a coefficient depending upon how the beam is supported, and how it is loaded; δ = maximum deflection allowed in inches; W = load in kg.; l = span in cm.; E = modulus of elasticity in kg./cm.^{2} and I = moment of inertia in cm.^{4} The values of K are given in the sub-joined table:—

TABLE No. 16

Condition of Beam	Coefficient K
Cantilever with load at free end	16
Cantilever with load uniformly distributed	6
Beams supported at both ends (load at centre)	1
Beams supported (load at ends uniformly distributed)	5/8

The following illustrative examples will make the procedure of design clear:—

Example: Design a teak beam to support a uniformly distributed load of 375 kg./m. run over a span of 4·5 m.

* By courtesy of the Forest Research Institute, Dehra Dun.

Take deflection $= \dfrac{1}{360}$ span.

Solution:

$$M = \frac{wl^2}{8} = \frac{375 \times 4{\cdot}5^2}{8} = 948{\cdot}75 \text{ kg. m.}$$

$$= 94875 \text{ kg. cm.}$$

Taking allowable stress $f = 125$ kg/cm² and $E = 113000$ kg/cm²

$$M = fz = f \times \frac{bd^2}{6}$$

$$= \frac{125 \times bd^2}{6}$$

$$\therefore \quad \frac{125\ bd^2}{6} = 94875$$

$$\therefore \quad bd^2 = 4554$$

Taking $d = 2b$

$$4b^3 = 4554$$

$$\therefore \quad b = 10{\cdot}44$$

Adopt a size 12×25 cm.

check for deflection:

$$\delta = \frac{5}{384} \times \frac{Wl^3}{EI} = \frac{5 \times 375 \times 4{\cdot}5 \times 4{\cdot}5^3 \times 10^6}{384 \times 113000 \times \dfrac{12 \times 25^3}{12}}$$

$$= 1{\cdot}16 \text{ cm.}$$

Allowable deflection $= \dfrac{450}{360} = 1{\cdot}25$ cm.

Hence the design is safe for deflection.

check for shear:

Maximum intensity of shear $= \dfrac{3}{2} \times \dfrac{W}{2A}$

$$= \frac{3}{2} \times \frac{375 \times 4{\cdot}5}{2 \times 12 \times 25}$$

$= 4{\cdot}22$ kg./cm² which is less than the allowable shear of 8:8 kg/cm.²

Hence the design is correct.

Design of a Steel Flitch Beam: This will be clear from the following illustrative example:

Example: (a) A teak beam of 35 cm. square section and sufficient length is available in stock, and is to be used across a span of 5·5 m. with simply supported ends to carry a uniformly distributed load of 13 tonnes. If the deflection is not to exceed $\frac{1}{480}$ of the span, and if $f = 125$ kg/cm² and E = 113000 kg/cm² calculate the load it will carry.

(b) If it is not sufficiently strong to carry the full load, design it as a steel flitch beam taking fs for steel = 1575 kg/cm² and E = $2\cdot1 \times 10^6$ kg/cm².

Solution:

Equating allowable deflection and actual one; we get—

$$\frac{550}{480} = \frac{5W \times 5\cdot5^3 \times 10^6 \times 12}{384 \times 113 \times 10^3 \times 35^4}$$

W = 7252 kg = 7·252 tonnes

The total load on the beam is 13 tonnes. Hence the load to be carried by steel plates = 13 — 7·25 = 5·75 tonnes.

As before

$$\frac{550}{480} = \frac{5 \times 5750 \times 5\cdot5^3 \times 10^6 \times 12}{384 \times 2\cdot1 \times 10^6 \times 6 \times 35^3}$$

$\therefore$ $b = 1.45$ cm

$\therefore$ Use a 15 mm m.s. plate.

Example: Design a double floor with 1st class C. P. teak on top of a room 6 m. × 5 m. used for an office.

Solution: Using one binder in the centre, the load on it will be due to that on an area of 3 × 5 = 15 sq. m.

Live load = 400 kg/m².

Dead load of joist and flooring = 150 kg/m²

$\therefore$ Load on the binder = 550 × 15 = 8250 kg.

Assuming a size of 20 × 40 cm., the self weight of the binder is = 0·2 × 0·4 × 5 × 610 = 244 say 250 kg.

$\therefore$ Total load on the binder = 8250 + 250
= 8500 kg.

$$M = \frac{8500 \times 5}{8} \times 100 = 531250 \text{ kg.cm.}$$

Allowable stress from Table 15 is $f = 100$

$$\therefore \quad \frac{100 \times bd^2}{6} = 531250$$

$$\therefore \quad bd^2 = 31875 \text{ cm}^3$$

Assuming $d = 2b$

$$4b^3 = 31875 \quad \therefore \quad b = 19 \cdot 98 \text{ say } 20 \text{ cm.}$$

Hence the required size is 20×40 cm.

check for deflection:

$$\delta = \frac{5 \times 8500 \times 5^3 \times 10^6 \times 12}{384 \times 121 \times 10^3 \times 20 \times 40^3}$$

$$= 1 \cdot 04 \text{ cm}$$

Allowable deflection is $= \frac{500}{360} = 1 \cdot 39$ cm.

Hence the design is safe for deflection.

check for shear:

Maximum intensity of shear stress

$$q = \frac{3}{2} \times \frac{W}{2A} = \frac{3}{2} \times \frac{8500}{2 \times 20 \times 40}$$

$$= 8 \text{ kg./cm.}^2$$

which is less than the allowable shear of $8 \cdot 4$ kg./cm^2.

To Design Bed Blocks: The bed block should be of the full width of the wall. Assuming the wall is 40 cm wide, the block will be $40 \times 30 \times 15$ cm thick either of concrete or cut stone. Its bearing area is $40 \times 30 = 1200$ cm.^{2}

$$\text{Stress} = \frac{8500}{2 \times 1200} = 3 \cdot 54 \text{ kg./cm.}^2 \text{ which is quite safe.}$$

Supposing that the ends of the binders rest for a length of 20 cm. on each block.

Bearing stress $= \frac{8500}{2 \times 20 \times 20} = 10 \cdot 63$ kg./cm.^{2} which is negligible.

To Design the Joists: The total load carried by the joists on one side of the binder $= \frac{8250}{2} = 4125$ kg. If the joists are spaced at 25 cm. centres in the space of 5 m., there will be 20 bays, the load on each bay will be $\frac{4125}{20} = 206 \cdot 25$ kg., Span $=$ 3 m.

$$\text{Maximum B.M.} = \frac{W.\,l}{8} = \frac{206\cdot25 \times 300}{8} = 7734 \text{ kg. cm.}$$

$$M = fz = f \times \frac{bd^2}{6} \qquad f = 100 \text{ from Table 15}$$

$$\therefore \quad 7734 = \frac{100\ bd^2}{6}$$

$$\therefore \quad bd^2 = 464$$

Assuming $d = 2b$

$$4b^3 = 464$$

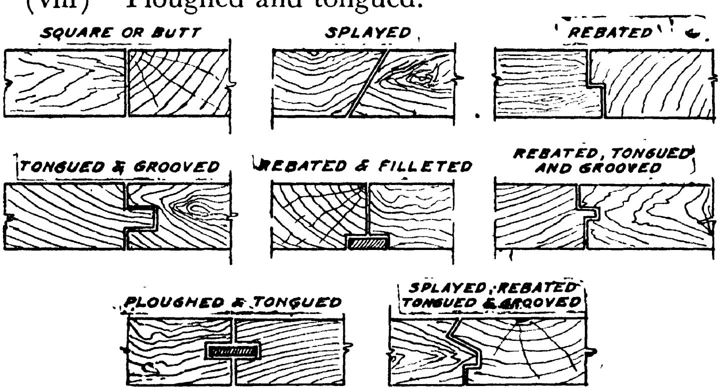
$$\therefore \quad b = 4\cdot88 \text{ say } 5 \text{ cm.}$$

Adopt a size of 5×10 cm.

20 joists will be required on each side of the binder. The design may be further tested for deflection and shear, as shown above, but as the span is only 3 m., it is not necessary.

The joints of the boarding are made in one of the following ways:

(i) Square or butt.
(ii) Splayed.
(iii) Rebated.
(iv) Rebated and filleted.
(v) Tongued and grooved.
(vi) Rebated, tongued and grooved.
(vii) Splayed, rebated, tongued, and grooved.
(viii) Ploughed and tongued.



Figs. 532—539:
Joints in boarding of floors.

The object of using a special joint in the floor board is to prevent the opening of the joint due to shrinkage of timber.

These joints are illustrated in Figs. 532 to 539.

In country houses, timber floors are used with a surfacing of *muram* or mud. The usual method of constructing these floors is to nail rough planking obtained from timber waste, planed on the underside, on the top of bridging joists, and to place a cushioning layer of about 10 to 15 cm. (4″ to 6″) of *muram,* on top of 25 mm. (1″) layer of wood shavings. The floor is finished in a manner similar to that described on page 210. The disadvantage of this floor is that the timber planking is liable to rot, the joints open with use, and through these, *muram* drops with every shaking of the floor.

Trimming of Timber Floors: Occasionally openings have to be left in floors for accommodating staircases, for fixing fire hearths, etc. In such cases the floor has to be trimmed.

Trimming is done by cutting short the necessary number of bridging joists and supporting them on a *trimmer joist,* which, in its turn, is supported by a *trimming joist.*

The width of the opening provided for accommodating a fire hearth should be such that no bridging joist lies within 50 cm. (1′ 6″) of any flue.

Fig. 520 shows the trimming for a fire hearth in a timber floor.

The sizes of the trimmer and trimming joist should be calculated for the load they are required to support.

(2) **Steel Girders and Wooden Joists:** There is not much difference between the wooden floors described above and this type of floor, except that the wooden beams are replaced by rolled steel girders. This makes the floors lighter and more economical. The wooden joists may either be simply placed on the top of the steel girders to be joined together by the wooden boarding nailed on their top, or they may be fixed by cast iron spikes. This, however, increases the depth of the floor unnecessarily and reduces the head room below the ceiling. To obviate this, angle irons are bolted to the webs to serve as cleats, and the ends of joists are placed on them, so that the tops of the joists and the top of the girder are at the same level.

For framed floors, the binders, which are also of rolled steel

joists, are bolted to the main girders, and wooden joists are fixed between the binders.

(3) **Steel Joists and Flagstones or Concrete:** In this type, if the span between the walls is small, say up to 3·75 m. (12 ft.), small steel joists of suitable section are placed on the walls to span the distance, usually at 30 to 50 cm. (1 to 1½ ft.), between centres.

If the span is longer than 3·75 m. (12 ft.), rolled steel beams of the required section are placed from wall to wall at a spacing of 2·5 to 3 m. (8 to 10 ft.), and between them, are laid smaller joists as above. The spaces between the joists are filled in one of the following ways:

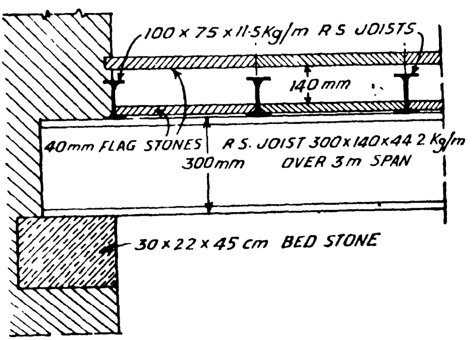


Fig. 540.

Flagstones 4 cm. (1½″) thick and of widths to suit the distance apart between the joists, are inserted from one end and placed on the lower flanges of the joists. After this a lean mixture of cement concrete about one inch thick is screeded on the sides of the joists so as to protect them from rusting by the action of the lime in the concrete. The portion above the flagstones is filled with light weight concrete of either crushed bricks or boiler slag in lime upto 12 mm. (½ in.) above the top of the joists, and the floor is finished in one of the usual ways. The joints are pointed with cement from below.

In this type, the concrete serves merely as a filler material and may be safely substituted by either *muram* or mud for economy, but the latter is likely to leak through the joints with the shaking of the floor.

In a modification of this type the flagstones are altogether dispensed with. Instead, temporary boarding is laid on vertical supports from below, between the joists, and concrete is

placed on it. If lime concrete is used, the boards can be removed on the tenth day.

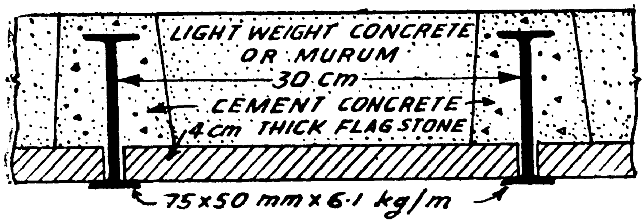


Fig. 541:
"Murum," mud, or light weight concrete may be filled above flagstone. Top finishing may be of tiles or flagstones.

In both varieties mentioned above, it is necessary to protect the steel joists from the action of lime by interposing a screed of cement concrete, or at least with a protective coat of bitumen or paint.

(4) **Floors of Steel Joists and Brick or Concrete Jack Arches:** These floors are constructed by turning brick or concrete arches on the lower flanges of M. S. joists spaced at not more than 1·25 m. (4 ft.) centres. The arches are given a very small rise, usually 1/12th of arch span. The floor is finished on the top with any kind of paving, such as stone, cement concrete, tile, etc., and the underside of the floor is plastered and white-washed.

The defects of this floor are that the ceiling of the floor is not plain from below, and the joists, if embedded in lime concrete, are liable to rust due to the action of lime. The arch action of the floor also exerts a thrust on the side walls, to reduce which, mild steel tie bolts have to be used in the end span at intervals.

The construction of jack arches of concrete is simple enough. The centering for the arches need not be supported on props resting on the ground floor, but it can be directly supported on the lower flanges on the floor joists.

The methods of constructing brick jack arches and concrete jack arches are as follow:

Construction of Brick Jack Arches: A segmental piece of timber about 4 cm. (1½″) thick, having the chord length equal to the span of the arch and the arc conforming to the soffit of the arch, is cut from a plank; and the ends of the segments are knocked off with a chisel for a length of 3 to 4 mm. (⅛″). This forms a centering board which should be laid on edge with the circular part upwards, on the lower flanges of the joists at a distance of 8 cm. (3″) from the wall. A mason should sit on a plank laid across the joists and start laying well burnt selected bricks previously kept immersed in water for 2 hours. The bricks be laid on

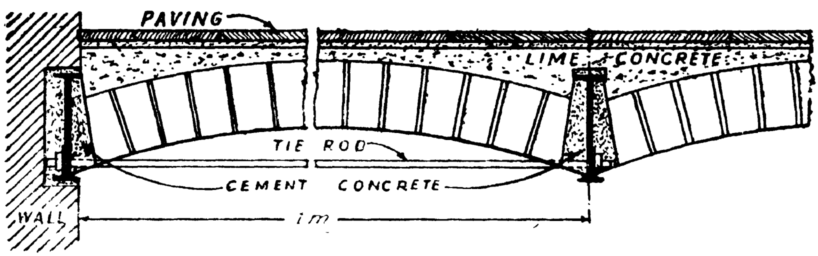


Fig. 542:
Steel joist and brick jack arches.

edge, and the work should start from both the joists and should close in the centre. The first ring should consist of alternate bricks 20 and 10 cm. (9″ and 4½″) long, respectively, so as to maintain a continuous bond between the first and successive rings. The end bricks should be cut to the required shape by means of a mason's axe so as to fit into the joist and project a little radially. The joint next to the joist should be filled with cement mortar so as to prevent contact of the joist with lime. When the work from both ends of each ring approaches the centre, the central brick known as the key, should be set in a rather stiff mortar, and the joints on both sides of the central brick should be tightly packed, if necessary with flat stone chips or brick bats set in mortar. The key brick should finally be given two light strokes of a mason's hammer.

After this, the arch ring should be supported by one hand, while with the other, the centering board should be pushed forward diagonally with light strokes of the hammer at one end until it is completely removed clear of the under surface of the arch ring. It should then be placed at about 20 cm. (9″) from its previous position, and the next ring of the arch, consisting of all 20 cm. (9″) long bricks, should be laid in a manner similar to that described above for the first ring. It should be noted that alternate bricks in this ring should interlock in the gaps left by the half bricks in the first ring. Successive rings should now be laid in the same manner. The last ring will again consist of alternate half and full bricks.

The arching should be kept well watered for about 10 days, and then the upper surface should be levelled with lean cement concrete or lime concrete and finished with the required type of flooring. The lower surface should also be plastered.

In the construction of these floors, the following points require careful attention:

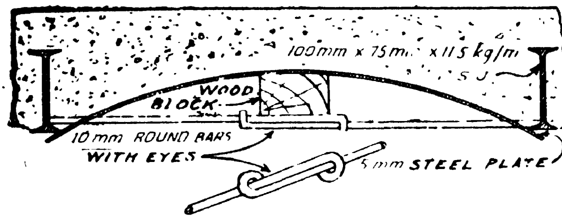
(1) The M. S. joist should not be allowed to come in contact with lime.

(2) Before starting the arching, the ends of the joists should be fixed on the top of the wall in 20 cm. (9″) thick masonry of cement concrete which must be given sufficient time to set.

(3) The extreme pair of joists on either side should be tied by three bolts, two at the ends of the joists and one in the centre. This prevents the end joists from being pushed out horizontally due to the thrust of the arch.

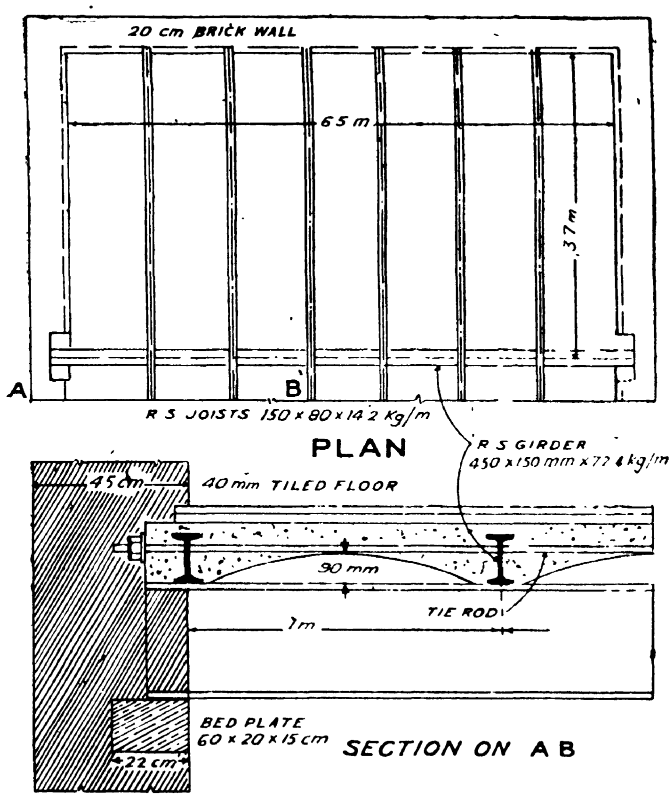
Construction of Concrete Jack Arches: The construction of concrete jack arches is comparatively simple. The centering for the concrete arches is made of 3 mm. (1/8″) thick M. S. plate bent to the required curve and having holes at the two ends, 75 cm. (2′–6″) centre to centre longitudinally. Two iron rods 12 mm. (1/2″) in diameter and of suitable length are hooked at the ends so as to form eyes large enough to pass a 12 mm. (1/2″) diameter rod (Fig. 544). Each rod is then passed through the eye of the other in such a way that by sliding the eyes towards or

away from each other, the total length of the two rods can be respectively increased or reduced. These rods are passed through



Figs. 543, 544:

Construction of jack arch of concrete between joists with steel centering fixed by special adjustable rods.



Figs. 545, 546:

Fire-resisting floor of steel joists and concrete arches. The joists are completely embedded into concrete.

the holes in the plate and supported on the lower flanges of the joists. In order to make the centering rigid, a wooden packing

piece is driven tight between the rods and the curved plate (See Fig. 543). The plate is now supported on the rods at intervals of 75 cm. (2′-6″), and it cannot spread out under the load as the joists would prevent this.

Concrete is now laid on the top of the centering to the required depth and the floor can be completed in the usual manner. After the concrete has set in about 10 days, the centering can be removed by knocking off the packing piece and by hammering the eyes in the rods toward each other so that the centering loses its support on the joists and can be easily removed. After the centering is removed, the underside of the arches should be finished with plaster, if desired.

The three precautions mentioned in the construction of brick jack arches also equally apply to this case.

Design of a mild steel joist or beam used in a composite floor is shown below :—

Example:—Design steel joists placed at 1 m. centres to support concrete jack arch floor 10 cm. thick with 3 cm. mortar screeding and 25 mm. mosaic tiles on the top across a span of 3 m. in an office building.

Solution:	Live load	400	kg./m.^{2}
	Dead load :—		
$\frac{10\text{ cm.}}{100} \times 2400$	concrete arching	240	,,
	4 cm. mortar screeding	66	,,
	25 mm. cement tiles	45	,,
	Self load (say)	49	,,
	Total load	800	kg./m.^{2}

As the joists are placed at 1 m. centres apart the load will be $1 \times 800 = 800$ kg./m.

$$\text{Max. B. M.} = \frac{wl^2}{8} = \frac{800 \times 3 \times 3}{8} = 900 \text{ kg./m.}$$

$$= 90000 \text{ kg./cm.}$$

$f = 1575$ kg./cm.^{2}

$$\text{Modulus of section, } Z = \frac{\text{B. M.}}{f} = \frac{90{,}000}{1575} = 57 \cdot 14 \text{ cm.}^3$$

From the table of properties of rolled steel sections an R. S. beam ISLB 125 125 mm. $\times$ 75 mm. $\times$ 11·9 kg./m. gives a sectional modulus of 65·1 cm.^{3} Hence it is suitable. The other properties of the section are:

web thickness = 4·4 mm

flange thickness = 6·5 mm

moment of inertia = 406·8 cm^4

Test for deflection:

Total load on the joist = 800 $\times$ 3 = 2400 kg.

$$E = 2 \cdot 1 \times 10^6 \text{ kg./cm.}^2$$

$$\delta = \frac{5Wl^3}{384\,EI} = \frac{5 \times 2400 \times 3 \times 10^6}{384 \times 2 \cdot 1 \times 10^6 \times 406 \cdot 8}$$

$$= 0 \cdot 9 \text{ cm}$$

$$\frac{\delta}{l} = \frac{0 \cdot 9}{300} = \frac{1}{333} \text{ which will do.}$$

Test for shear:

Reaction = 1200 kg.

Assuming that whole shear is taken by web.

Area of web = 9·54 $\times$ 0·44 = 4·20 cm^2

$$\therefore\ q = \frac{1200}{4 \cdot 2} = 285 \cdot 7 \text{ kg./cm.}^2 \text{ which is safe}$$

Hence use 125 $\times$ 75 mm $\times$ 11·9 kg. joist.

(5) **R. C. C. Floors:** Obtaining an effect of continuity in slabs and beams, making the panels as nearly square as possible, and reducing the span in the direction in which the main reinforcement is provided, to a minimum, are the three guiding principles of economic design of R. C. C. floors.

R. C. C. floors may be classified into three main divisions:

(1) Beam and slab floor, of which the T-beam floor is a variety.

(2) Floors with the gaps between concrete ribs filled with hollow tiles or steel cores.

(3) Flat or beamless slabs.

(1) *Beam and Slab Floors:* In these the beams and slabs are designed as rectangular sections. However, in monolithic construction, the slabs and beams are cast together, and there-

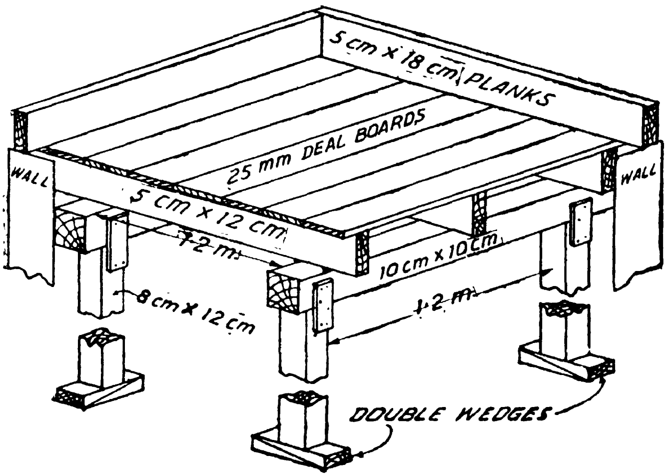


Fig. 547:

Typical form work for a slab. Double wedges are placed below vertical supports, to enable the form work being tightened or removed without jerks.

fore, we may consider a certain portion of the slab adjoining the beams on either side as adding to the compressive area of the latter. The exact proportion depends upon the specifications. This is what we call a T-beam. By utilising part of the slab, we require a smaller section of the beam, but this, in turn, results in increasing the steel reinforcement due to the reduction in depth, i.e., in the lever arm.

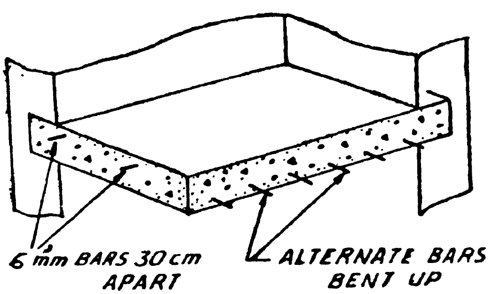
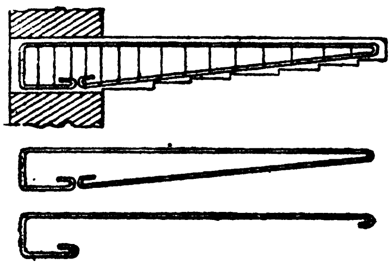


Fig. 548:
Isometric section of a solid R. C. C. slab.

The shorter the span, the stronger and more economical is the floor. The maximum economic span for a slab is 3·7m. (12″).

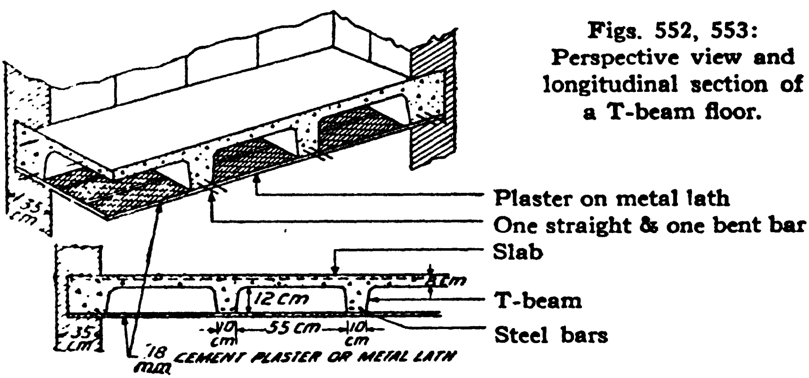
Attempts are made, therefore, to reduce the span to this limit. It is done from the following considerations:

If the span to be slabbed is oblong, with width less than 3·5 m. (12 ft.), the width is taken as the span and the main reinforcement is provided in that direction, e.g. in the apartments: 2·5m.×4·25m., 3m.×5m., 3·75m.×5·5m., (8′ x 14′, 10′ x 16′, 12′ x 18′) 2·5 m., 3 m. and 3·75 m. (8′, 10′ and 12′) are taken as the span.



Figs. 549—551:
Section of a cantilever slab showing reinforcement and vertical stirrups.

(ii) If the width of such oblong spaces exceeds 3·75 m. (12 ft.), intermediate beams are provided at not more than 3·75 m. (12 ft.) apart, and the distance between the beams is taken as the span. Thus in an apartment of 4 m. × 5·5 m. (13′ x 18′), one central beam would make two bays of 4 m. × 2·75 m. (13′ x 9′) each; in a 4·6 m. × 7·2 m. (15′ x 24′) room, one beam would make two bays of 4·6 m. × 3·6 m. (15′ x 12′) each, or two beams would make three bays of 4·6 m. × 2·4 m. (15′ x 8′) each. In these cases 2·75 m., 3·6 m. and 2·4 m. (9′, 12′ and 8′) would be the spans.



Figs. 552, 553: Perspective view and longitudinal section of a T-beam floor.

But, oftentimes, the uneven, ribbed surface of the ceiling is unsuitable either from the decorative point of view, or convenience of lighting, and so, if a flat ceiling is desired, No. (iii) is adopted.

(iii) The space is divided into panels each of approximately equal length and breadth, as far as possible, and the reinforcement is divided in both directions. This makes the slab stronger even with a smaller depth. As the length of the panel increases, the advantage is progressively reduced, until it altogether ceases when the length is equal to twice the width. Thus in an apartment of 4·6 m. $\times$ 10 m. (15′ x 32′), and 4·9 m. $\times$ 10 m. (16′ x 36′), introducing one central beam or wall would divide the area into two nearly square panels of 4·6 m.$\times$5 m. (15′x16′) and 4·9 m. $\times$ 5 m. (16′ x 18′) each, respectively.

For live loads of 500 kg./cm.^{2} (100 lbs. per sq. ft.) or more, a beam and slab floor is more suitable, and even more economical than a flat slab under the following circumstances, unless architectural treatment requires it otherwise.

(a) When there are many large openings in the floor, such as for staircases, lifts, escalators, day-light court yards, etc.

(b) When the spans are very long.

(c) When the panels are oblong, or irregular in shape.

(d) When the floor has a width of only one panel.

(6) **Floors With Concrete Ribs Filled With Pre-cast Units or Sheet Cores:** In the beam and also slab construction, the concrete below the neutral axis is considered as having no tensile value, except to resist shear stresses. When the live load is light, the shearing stresses in the concrete are small, and therefore a certain portion of this concrete may be removed, leaving a sufficient number of ribs or concrete joists at short intervals carrying reinforcement to take care of these stresses. The required area of reinforcement is reduced owing to the reduction in the dead weight; but, at the same time, the diameter of the individual steel bars is increased due to the restricted width of the ribs. We have now a number of closely spaced concrete ribs connected at the top by a thin, reinforced concrete slab.

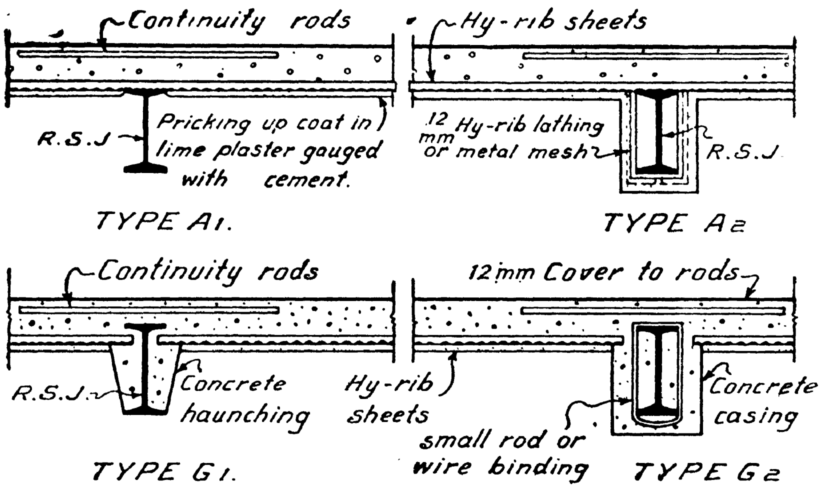
As the tension in the concrete below the neutral axis is neglected, it is possible to fill the gap with light-weight units of hollow tiles or steel sheet cores. They are particularly welcome if they can eliminate the expense of shuttering, and afford an effective protection from fire, for the slab. There are a number of hollow tiles, such as burnt clay tiles, gypsum tiles, concrete hollow tiles, etc., on the market, to fill these gaps.

Thus Caxton hollow tile floors consist of reinforced concrete T-beams whose webs are separated by rows of burnt clay hollow tiles.

The truscon hollow floors are also of reinforced concrete ribs of T-beam formation, with a suspended ceiling below the hollow portion. The arrangement is very much suited to the concealment of domestic services, such as electric wire, gas, water pipes, ventilating ducts, lighting panels, etc. The floor is laid *in-situ.*

The Kleine floors of hollow bricks and the Big-span floors of hollow burnt clay blocks, are other floors constructed on the same principles.

Among floors of metal sheet cores or steel sheet or mesh reinforcement, the following may be mentioned:



Figs. 554—557:
Four different types of Hy-rib floors.

The Hy-Rib, as illustrated in Figs. 554 to 557 can be used either flat or curved in conjunction with either steel joists, timber or R. C. C. ribs. The great advantage with Hy-Rib is the saving in timber centering. The only timbering required is temporary runners at about 60 cm. (2 ft.) centres to support the Hy-Rib while being concreted.

Expanded metal standard has served different types design-ed either as simply supported at ends or continuous floors.

Jhilmil R. C. flooring consists of R. C. slabs, strengthened at intervals with segmental concrete arches turned on channel steel ribs as temporary supports. Jhilmil metal fabric is wired to light metal bearers clipped to R. S. Joists.

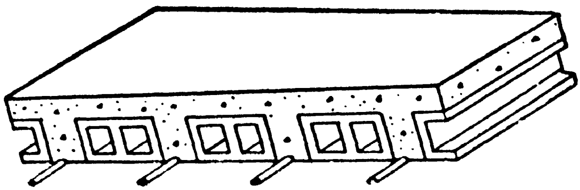


Fig. 558:
King hollow floor tubes.

The king self-centering flooring system (Fig. 558) is composed of King hollow floor tubes laid between R. S. joists spaced at 1 m. (3 ft.) centres. A covering of cement concrete is laid over the tubes to form a flush top surface.

Self-centering floors are constructed without the use of shuttering to support it during construction. The mesh is prepared from steel sheets of 1·1 mm., 1 mm., and 0·9 mm. thickness (24, 26 or 28 gauge), and has nine ribs to give it necessary stiffness. The outer ribs of each sheet interlock with those of the adjacent sheets. The ribs are connected by diamond-shaped expanded metal. The width of each sheet is 0·71 m. (2 ft. 5 in.), and lengths vary from 1·8 m to 3·6 m. (6 to 12 ft.) The sheets are adaptable to timber or steel joists, or even to R. C. C. ribs. There are two types: flat and arched. The arched type is suitable for heavy loads such as of warehouses, factories, etc.

The design of the above type follows the principles of T-beam floors. The standard width of ribs is 10 cm. to 12 cm. (4 to 5 in.), so that the distance between centres equals 60 cm. (24 or 25 in.) The slab between the ribs is 5 to 10 cm. (2 to 4 in.) thick and its reinforcement is usually of wire mesh. In some systems 10 mm. (3/8 in.) straight bars are used instead, and laid perpendicular to the ribs at 45 to 60 cm. (18 to 24 in.) centres. This type is not suited to heavy moving loads.

The light floor construction described above is found economical for live loads up to a maximum of 600 kg./m.^{2} (125 lbs.

per sq. ft.) and with spans up to 9 m. (30 ft.) long. The advantages of this type are:

(a) Uniform head room, and consequent even distribution of light.
(b) Light, rigid construction with saving of concrete.
(c) Sound-proof due to the dead air space below the tiles.
(d) Affords room for service pipes between the ribs.
(e) Effectively fire-resisting.
(f) Formwork very simple and cheap.

The structures for which this type is most suited are those having fairly distributed loads up to 600 kg./m.^{2} (125 lbs. per sq. ft.), such as in hospitals, schools or office buildings, hostels, residential flats, etc.

(7) **Flat or Beamless Slab Floor:** When the load on a reinforced concrete slab is conveyed directly to the supporting columns without the agency of beams or girders, it is called a *flat slab.*

There are several systems of flat slab design, but the most used are (1) the two-way system and (2) the four way system. The second is the more common in use. The tops of columns are usually flared to give good bearing to the slab. This flare is called a capital. As an added assistance to carrying the load, a portion of the slab, symmetrical with the column, is thickened, producing what is called a drop panel.

In the two-way system, the width of the beams is usually taken as half the width of the panel. This leaves an area in the centre of the panel which is regarded as supported on four sides. In the four-way system, the area in the centre of the panel is supported by two wide beams running diagonally between the columns. The diagonal bands and one half of each of the four straight bands cover the whole area of the panel.

The slab reinforcement usually consists of a large number of 8 mm. (3/8 inch) bars, a large percentage of which radiate from the various column capitals and are located in the bottom of the slab at mid-span, and in the top of the slab across the capitals. Short lengths of reinforcing bars are necessary in the top of the slab at right angles to, and over the direct bands, as tensile stress may occur here, due to the relative stiffness of the direct bands to the diagonal ones.

This type of slab is suited to industrial and manufacturing buildings, warehouses, cold storages, theatres, etc.

The principal advantages are:

(1) The flat ceiling gives better lighting facilities.

(2) For the same clear head room, there is a considerable saving in the storey height.

(3) The system, particularly the four-way system, distributes load evenly and interlocks so many small bars; thus the slab is stronger than the ordinary one with the same amount of reinforcement.

(4) The form work is very simple.

(5) With approximately uniform and equal spacing of columns and few large openings in the floor, this type of construction is more economical for live loads of 500 kg./cm.^{2} (100 lbs. per sq. ft.) or more, and spans of 4·5 to 9 m. (15 to 30 ft.)

Reinforced Brick Floor: This is briefly dealt with later in the chapter on "Cement Concrete, Plain and Reinforced."

Questions for Revision

(1) Explain the difference between single, double and framed timber floors. Why have these floors fallen into disuse?

(2) Design a beam-and-bridging-joist floor with beams at 2.5 m. centres on a room 4·25 m. wide for a total load of 600 kg./cm.^{2}

(3) How are brick jack arches constructed without a regular centering? What precautions are necessary for jack arch construction? Sketch adjustable steel centering for jack concrete arches.

(4) Design a double floor with steel beams at 2·25 m. centres on the top of a room 4·5 m. × 6·5 m. using teak wood joists at 30 cm. centres. Take the total load as 700 kg./cm.^{2}

(5) What is a flat or beamless R. C. C. floor and what are its advantages?

(6) Sketch a cross section of a steel joist and double flagstone floor with joists of 12 cm. × 4 cm. section placed at 30 cm. centres.

PLASTERING, POINTING, DISTEMPERING : 14

PLASTERING is the covering with material of various compositions applied either externally or internally to walls, partitions of lath, ceiling, etc., to hide the irregularities of the surface.

The object of plastering walls externally is to seal the surface so as to enable it to resist the atmospheric influences, particularly the infiltration of rain, and also to obtain a decorative effect. The object of plastering the inner surface is (1) from a sanitary point of view to provide a smooth surface which does not allow dust, dirt, and vermin to lodge on it, and (2) from a decorative point of view, to prepare it for the application of white or colour wash, distemper or paint.

The requirements of an ideal plaster are that it should be smooth, non absorbent, reasonably sound-deadening, flame-retarding, washable, and not affected by rise or fall in temperature.

The main types of plaster are three: (1) Lime plaster, (2) Cement plaster, and (3) Mud plaster. Besides these, there are many types of patent plasters in use, and recently fibrous slabs and various wall boards are superseding plaster, as the latter serve the additional purpose of insulation against heat or cold, and noise.

Preparation of Surface: Whether for exterior or interior work, the surface is prepared by first, knocking off projections which are more than 12 mm. (½") beyond the general surface of the wall, whether of stone or brick; for if this is not done, the plaster must be sufficiently thick all over the wall to cover them. This not only increases the quantity of material, but the thicker plaster is more likely to fall off. Next, the mortar from the joints should be raked out at least to a depth of 18 mm. (¾ of an inch) to give a key to the plaster. The surface should then be freely wetted with water and it is then ready for receiving the first coat.

Interior Work: For interior work, cement is not usually employed, or if used, it is not used in the finishing coat; for, distempers and colour washes, etc. do not stick so well to cement plaster. Cement is used even for the finishing coat of plastering the inner surface, only where water-tightness is required, e.g. in bathrooms, W. Cs., cellars, drains, water cisterns, etc.

For lime plaster, fat lime of pure chalk or sea-shells is the best. Hydraulic lime, though strong and hard, if used, contains particles which might slake very slowly—even after six months or a year, and the surface of the plaster may be damaged by blisters called *blowing*. Hence, to avoid this risk, lime mortar is first ground in a mill, left in a heap for two or three weeks, and reground before use.

Lime plaster is applied in three courses. The first, which is called the *rough course,* consists of coarse sand and lime in the proportion of 1:2 in which about 1/16th part of cement is mixed. This is dashed against the wall surface in a layer of 6 to 8 mm. (¼ to ⅜ in.) just to serve as a key to hold the next courses firmly to the wall surface. It is frequently watered and left exposed to air to set and harden for two days. In England, and on the Continent, oxhair is mixed in this course, and it is applied in a thickness of half an inch.

Before applying the second coat, the surface should be watered, and a few small patches or dots say about 50 $cm.^2$ (4 to 6 sq. in.) in area, are applied here and there about 5 feet apart on the wall to serve as gauges for guidance of work. These are carefully laid so that their surfaces are in one plumb plane. If just a little cement is mixed in the mortar used for the patches, they set and harden sufficiently within half an hour. Then the material is screeded in the spaces between the patches and by means of the plasterer's float (Figs. 565, 566) it is levelled true to the surface of the bench mark patches.

If the lime is not of good quality, *gugal (Amyres agallocha)* is added when the mortar is being ground, in the proportions of 4·5 kg. (10 lb.) of *gugal* to 2·8 $m.^3$ (100 cu. ft.) mortar. Oftentimes, a solution of *gur (jaggery),* about 125 gm. (¼ lb.) to 5 lit. (a gallon) of water, is added to the mortar to thin it before screeding and this improves its adhesion.

The second or the *floating course* is then applied by screeding lime mortar. It is about 9 to 12 mm. (⅜ to ½ in.) thick in

the case of brick-work, and slightly more for stone-work. At any rate, it must be sufficiently thick to cover all the projections.

Fat lime shrinks as it dries up, and it is very likely that small cracks will appear on the surface of the floating coat. It is therefore, beaten by the edge of a wooden tapper and close dents are made on the surface. This helps the plaster in several ways: The cracks are closed, the lime is compacted and driven home into the joints, and the dents serve as a key to the subsequent coat.

About 4 to 5 days after the second or floating coat is applied, the final or finishing coat, consisting of cream of white or fat lime (*n e e r u*) and fine white sand in the proportion of 1 : 2, is applied very thinly (about 3 to 1·5 mm. or ⅛ to 1/16 in.) with a mason's trowel and polished.

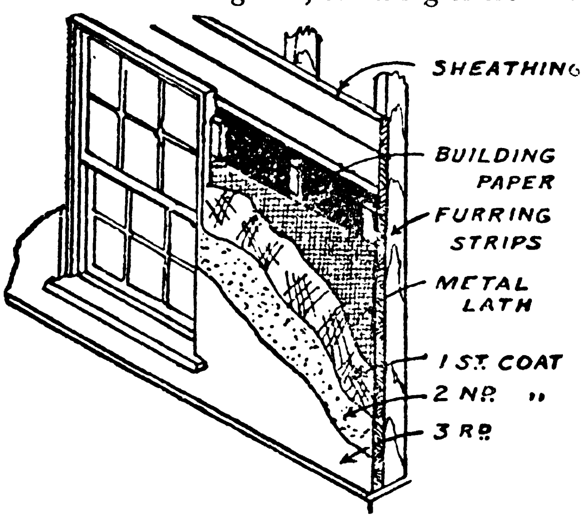


Fig. 559:
Three coats of lime plaster on metal lath.

Oftentimes a little powder of mica is mixed in the material of the final coat, the particles of which shine in strong light.

If a very smooth surface is required, ground soap-stone is held in a piece of muslin and sprinkled, and the surface polished.

Plaster on Lath: The lath may consist of either wood or metal. The modern tendency is to discard wooden laths in favour of metal lathing. Particularly in this country, on account of the tropical climate, wooden laths are subject to excessive swelling or shrinking, which causes cracks in the surface of the plaster; besides, wood is liable to decay or be attacked bv white ants. Hence, plaster on wooden laths is rarely practised in this country in all but very unimportant structures.

The wooden laths, when used, are thin strips of well-seasoned wood about 25 mm. (one inch) broad, 1 m. (3 to 4 ft.) long, and of thickness according to the size used, viz., (1) *Single,* average 3 to 5 mm. (1/8 to 3/16 in.) thick. (2) *Lath and half,* average 6 mm. (1/4 in.) thick, and (3) *Double,* average 8 to 12 mm. (3/8 to 1/2 in.) thick. They are laid in parallel lines with a space of 8 mm. (3/8 in.) between, fixed to wooden frames by galvanised wrought iron nails 18 to 30 mm. (3/4 to 1 1/4 in.) long according to the size of the laths used, with staggered butt joints.

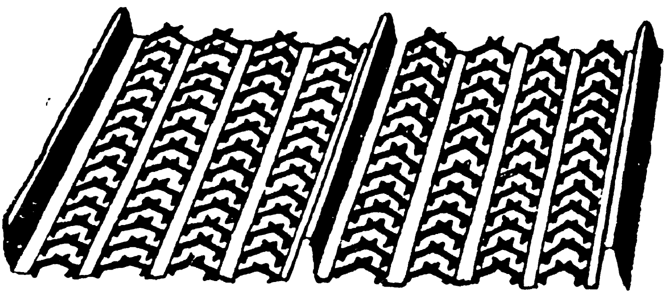


Fig. 560:
Hy-Rib metal lath.

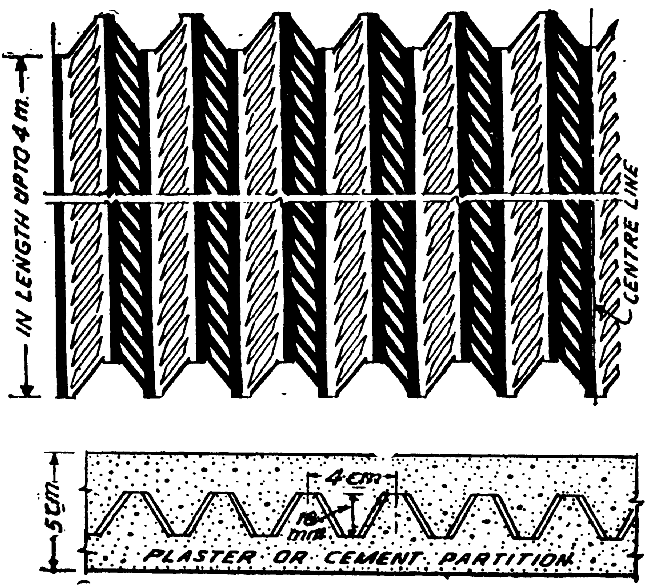
Metal lathing is of various types, but expanded metal is by far the most extensively used. Other varieties are: B. R. C. fabric, Hy-Rib, Self centering, Trussit and Wire Gauze Netting. The sheets are drawn taut and fixed by G. I. staples driven into wooden supports. When the latter are not available, wooden plugs or fillets should be embedded in the concrete or brickwork. If the lathing is loose, the plaster is bound to crack. The sheets should be joined by a reasonable lap, and should be fastened by lacing with a galvanised wire through the meshes. Joints should not be formed at corners, where two surfaces—either vertical or horizontal—meet, the lath should be bent at the junction.

In the case of suspended ceilings, round or flat mild steel rods are suspended by means of hangers from joists, and the metal lathing is fixed on to them.

The plaster on laths, whether of wood or metal, may consist of two coat work specified as lath-plaster and-set, or lath-float-and-set; or three coat work specified as lath-plaster-float-and-set. The last coat of *set* is the same as the finishing coat of *neeru* on wall surface already described.

The process of plastering on lath is the same as on wall surface, except for the addition of lathing in the beginning. The first coat takes a longer time to set as there is no sucking action as in the case of brick or stone wall.

Cements and Special Materials Used in Plastering : (1) *Plaster of Paris:* This is calcined gypsum. It swells greatly and sets rapidly, so it is mixed with ordinary lime and used for moulding cornices. In this country, it is not much used except for repairing small holes in old plastered surfaces.



Figs. 561, 562:
"Trussit."

(2) *Keen's Cement* is plaster of Paris saturated with alum and used only internally for angles, pilasters, and more ornamental parts, where a smooth, hard, and white surface is required. It is mostly used for the finishing coat. It sets quickly.

(3) *Parian Cement* is also a plaster of Paris, calcined with borax. It is cheaper than Keen's cement, and is, therefore, used internally even for large surfaces where Keen's cement would be costly.

(4) *Barium:* Barium plaster is employed as a finishing

coat to the walls of X-ray rooms for the protection of people engaged in X ray work.

(5) *Sirapite:* Sirapite is a compound of gypsum slaked in petroleum. It is easy to work, and sets rapidly. It possesses high fire resisting properties and dries with a hard, white surface.

(6) *Martin's Cement:* Martin's cement is similar in preparation to Parian, pearl ash being used instead of borax. It sets quickly and dries with a hard, white surface. It is used for the surface of dado and flooring.

(7) *Thistle Hardwall Plaster:* This is manufactured also from high grade gypsum rock, and has a high sand carrying capacity. It sets quickly, and gives a marble-like polish.

(8) *Asbestos-marble Plaster:* A new plastic wall finish, consisting of finely crushed marble and asbestos mixed with cement, has recently been introduced. It may be applied either with a brush or a sponge as the finishing coat on a cement or lime surface, and polished when set, to give a beautiful decorative effect.

(9) *Snowcrete* and *Colorcrete Cements* are used for external work, and the process of applying may be learnt from the instructions supplied by the manufacturers.

(10) *Granite Silicon Plaster :* This is a quick-drying, hard-setting material, possessing considerable elasticity, so it is not liable to crack.

(11) *Acoustic Plaster:* A hard, dense and highly polished finish is very bad in churches, music halls, theatres, and the like, as it causes unpleasant reverberations and interferes with clear hearing. A few special acoustic plasters are on the market, which, when guaged, produce gases. The gases cause air bubbles in the plaster mass and honeycomb it. The surface thus formed absorbs sound waves.

External Work: For external plaster, called rendering, Portland cement is the most suitable material. Usually one coat is sufficient, but for a finer finish two coats are applied. For the first coat, cement is mixed with sand in the proportion of one of cement to 3 to 4 of sand, and screeded on the prepared surface to form a coat of about 15 mm. (5/8 in.) average thickness, worked with a float and well watered. Upon this the second coat of one of cement to two of sand, known as the finishing coat (about 6 mm. or 1/4 in. thick), is applied and worked with a

wooden hand float. A steel float, or trowel, is liable to cause crazing. The cement may be water-proofed by mixing a suitable water-proofing compound, if desired; but if properly mixed and applied, it is not essential.

There are a number of varieties of finishes. The principal among them are *rough-cast, smooth-cast, pebble-dashed, sand-faced* and *depeter.*

In *Rough-cast,* cement and coarse-grained sand, mixed in the above proportions, are screeded or dashed with force on the surface, and the surface is roughly levelled by light movements of a wooden float. This is applied in a single coat. A water-proofing compound and some earth colour may be mixed, if desired.

In *Smooth-cast,* instead of coarse sand, fine-grained sand is used. Sometimes this is done in two coats, the first of lime or cement mortar just as a floating coat, and the second of cement and fine sand (1:3) worked by a wooden float but not made smooth.

In *Pebble-dash,* the wall receives a rendering of coarse sand and cement (1:3) about 12 mm. (½ inch) thick, and against this, clean and washed pebbles are dashed by means of a scoop.

In *Sand-faced* plaster, on the first rendering of the coarse material, washed, fine sand is dashed, and the surface is made even with a float.

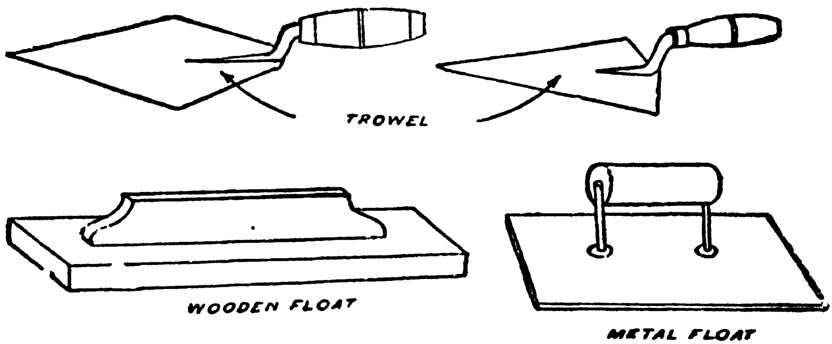
Depeter is a form of rough cast on which gravel or broken flint is pressed by hand while the rendering coat is still wet. Simple or elaborate ornamental patterns may, in this way, be formed in colour.

Various beautiful and ornamental patterns and textures may be worked on the rendering coat by using different tools and making movements of hand with ingenuity. The tools employed are rubber sponges, old distemper brushes, grass brushes or scratching tools.

The plasterer's tools are shown in Figs. 563 to 566.

Guniting is plastering by spraying with a nozzle attached to a drum of compressed air. The machine is known as a cement gun. It consists of a hopper through which a dry mixture of cement and sand is fed, and a lower chamber fitted with valves

into which air is compressed. A hose, with a nozzle attached at the end, is fitted to this chamber. The nozzle has two concentric openings. The dry mixture from the hopper is ejected through the central opening, and a jet of water is forced through the circumferential opening round the central. By means of valves



Figs. 563—566: Plasterer's tools.

attached to the nozzle, either the jet of water or the spray of the dry mixture can be regulated. With sufficient practice a mixture of the proper consistency can be formed and sprayed with force in a layer of any desired thickness. It is claimed that as the material is sprayed with great force, the plaster is compacted, and results in a water-tight layer and makes it unnecessary to add a water-proofing compound, even when the walls of a deep water reservoir are to be rendered water-tight.

Wall Boards : Though plaster forms the best covering externally on brick walls it is not a very satisfactory material on the interior of a building for the following reasons:

1. In a climate like that of India, the great difference between the maximum and minimum temperatures causes excessive expansion and contraction, with the result that bad cracks soon appear, allowing lodgment for dust and vermin, and destroying decorative schemes.

2. It does not stick well to woodwork, and so, wherever it comes in contact with woodwork, it becomes loose.

3. The operation of plastering is a slow one. It involves application of three coats, and setting periods have to be allow-

ed between each laying on; thus the time required is considerable.

4. During the process of screeding material, any finished wood or polished metal work has to be covered up for fear of being stained by the splashing of the material.

5. A great deal of water has to be used in its composition, and so drying out of the building to a state fit for occupation, is delayed.

6. A hard, smooth, and polished surface is ideal for decoration, but it is very bad for insulation both against heat and noise; further it causes condensation in cold countries.

To overcome these disabilities a variety of wall board composed mostly either of crushed organic fibrous material or asbestos, mixed with some binding material, compressed and rolled into sheets of large sizes, has been increasingly coming into use recently. Some of them are not only lighter, stronger and more decorative than plaster, but are also resilient, non-absorbent, fire-resistant and sound deadening. Instructions regarding their use and application are obtainable from their manufacturers.

Mud Plaster : The preparation of the surface should be done by knocking off projections and raking joints, etc. as in the case of lime plaster. The surface should be sparingly wetted with water.

The material consists of clay, which, if very stiff, should be mixed with some sand. All the clods, should be broken and it should be sifted through a sieve of 12 mm. (½ in.) mesh so as to exclude stones and bigger lumps of clay. Then a large heap should me made, say about 1 m. (3′) high, and the hollow at its top should be filled with water which should be replenished as its level goes down. This is very helpful if the clay contains some salts in it. This should be left for a week. Then chopped straw, hay, loose coir, hemp, or pine needles, etc. should be mixed with it. The material which is then ready for plaster should be evenly dashed against the wall surface and worked with a wooden float. After 24 hours, the surface should be tamped and close dents made with an edged instrument. Tamping helps in compacting the layer and driving it home into the joints which serve as a key to hold the plaster firmly to the surface. Even if a patch has caked

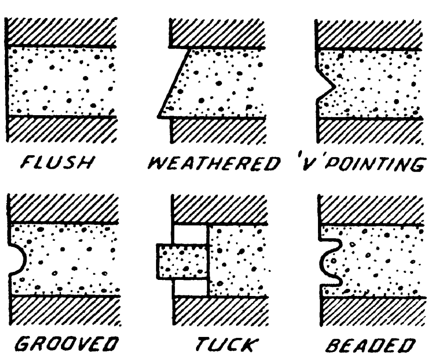
and sounds hollow, tamping will cure it. If large cracks are formed, they should be filled with a mixture of two of clay to one of cow-dung.

After tamping, a thin wash of cow-dung should be given, and tamping done again at the places where small cracks have developed. The final treatment consists of a wash of white earth, cow-dung, and cement in the proportion of 3:2:1.

Pointing: The joints on the face of stone or brick masonry are roughly filled in, while the walls are being raised. If they are afterwards neatly finished off, the work gives a better appearance. However, the principal object of pointing is to prevent rain-water from entering the interior of the masonry through the joints which form the only weak spots on the exposed face of stone or brick masonry, provided the bricks are of good quality.

Preparing the Wall: All joints on the face should first be raked out with a nail to a depth of 20 mm. (¾ in.) In new work, this should be done before the mortar sets, so as to make a proper junction between the wet mortar in the masonry and the fresh mortar. The wall surface should then be cleaned and thoroughly wetted, and all loose mortar or dust should be brushed out of the joints.

Mortar : If lime is to be used, it should preferably be of the fat variety, and should be thoroughly ground with an equal volume of fine sand. The grinding should be well done so as to crush the sand and leave no grit in the paste. Cement mortar should be composed of one part of cement to 2 or 3 of fine sand. (Vide (8) on page 122.)



Figs. 567—572:

Different varieties of common pointing or finishing of joints in masonry face.

Application : The mortar should be laid inside the joints with a small trowel, well pressed in and rendered smooth, finishing off the joints neatly in one of the following ways:

The surface should be kept wet for a week if cement is used, and for three days if fat lime is used.

Fig. 568 is an enlarged section of *struck* or *weathered pointing,* in which the mortar is pressed in with a trowel, and the lower horizontal edge is cut straight.

Fig. 570 represents a section of a grooved joint. The mortar is first pressed in with a trowel, and then the bent end of a small rod (usually 6 mm. or ¼ in. diameter) is pressed and rubbed in the middle of the joint frequen ly until a dark, round notch of uniform width is made. The tool is called *naila.*

V-pointing is shown in Fig. 569 and *beaded pointing* in Fig. 572. One more mode of pointing is known as *tuck pointing* shown in Fig. 571. In this after the ordinary mortar has been pressed into the joint or scraped out, and the joint stopped up flush with mortar, a straight edge is held horizontally along the joint, and thin, white, lime putty is laid on its top and pressed into the joint after which the top edge is cut off level, leaving a projection of about 3 mm. (⅛ in.) outside as shown in the figure.

White-washing, Colour-washing and Distempering :— *Preparation of Surfaces :* The surface should be clean and thoroughly dry. If it is extra smooth, coats will not stick to it. In that case it should be lightly rubbed with sand paper. For re-white-washing, the surface should be cleaned of all loose old wash, and sand papered, all nails removed, and holes filled with lime putty in which the same amount of fine sand and a little *gur (jaggery)* is mixed. Otherwise, cracks due to shrinkage will appear. If the patches are large, the wash should not be applied until they are reasonably dry.

Application: The wash to be applied with a brush in two coats—one vertical and the other horizontal. Each coat must be allowed to dry before the next is applied. Three coats are required for new work and for work on scraped surfaces. Annual white wash may consist of one coat only, applied first in vertical strokes of the brush, followed immediately by horizontal strokes.

Materials : For white washing, fresh quick-lime in unslaked condition is required. Lime obtained by burning shells in a kiln should be preferred as it is white and free from impurities. It should be put into a tub, and plenty of clean water poured on it. When slaked, it should be stirred and thinned by adding

water to a consistency of cream. It should then be strained through *khaddar*. Then a solution of either 1 kg. (1 lb.) of gum arabic or glue dissolved in water, or size, made of 1 kg. (1 lb.) of rice flour, should be added to 55 lit. (1 c. ft.) of the liquid.

A lit le blue or *tootia* (copper sulphate), if added, prevents glare and gives it a pleasing effect.

A little alum, or common salt, say, 100 gm. (¼ lb.) to 22·5 lit. (a c. ft.) of the liquid wash, if added, causes it to stick well.

In kitchens, where the walls have become discoloured by smoke, a wash of a mixture of wood ashes in water should be applied before a new coat is given.

For preparing colour wash, the necessary pigment or colour is to be added to the white wash prepared as above with gum, glue, or size. With some colours, rice size causes streaks; it should, in that case, be substitu'ed by gum or glue. A cheap buff wash may be prepared by adding *peeli* or *Multan mitti*, also called *ramraj* in North India.

A cheap, light olive green wash is made by adding a paste of crushed droppings of goats in water after straining it in a coarse cloth. It might be objected to from a sanitary point of view, but when dry, it is as good as clay or earth.

For slate colour, add lamp black and blue.

For a green wash, boil about 2.5 kg. (10 lbs.) of fresh mango bark in 1 lit. (4 pints) of water for 5 minutes, and mix the water together with a solution of 0.5 kg. (2 lbs.) of copper sulphate (*tootia*) in .75 lit. (3 pints) of water.

Sufficient colour wash should be prepared to cover a room at a time, and never more than the quantity required for one day.

Distempers are obtainable ready-made. They have one advantage that the shade is uniform. But they are costly. Some of them are really *washable*, i.e., the distempered surface can be cleaned by rubbing it lightly with a clean cloth dipped into water. This should not be done within three months of the application of the distemper. It takes that period to set.

Oil-bound Distemper is a form of oil paint in which the drying oil is emulsified, i.e., rendered mixable with water. It is supplied in a stiff paste which can be thinned with water. When water dries out, the oil gradually hardens and makes the surface washable.

Bituminous Water Paint: Bitumen is emulsified to form a water-proofing paint after drying for use on exposed walls.

Wall Tiling: Walls are sometimes lined with tiles either partially up to 1.25 m. (4 ft.) above the floor level, or up to the ceiling, in passages, bath-rooms, swimming pools, kitchens, staircases, boiler rooms, fire-places, and sometimes on the exterior of buildings for decorative effect or protection from atmospheric influences. They make the wall non-absorbent and easy to clean.

The tiles used are either of terra cotta, faience, or china-clay. Faience is similar to terra cotta, but it is twice fired, i.e., the block or slab, after it is moulded, is first burnt in a kiln, then coated with a glazing material, and burnt again a second time. Faience has a very wide range of colours.

China-clay tiles have either a glazed or matt surface, and are available in a large number of colours. The normal thickness is 8 mm. (3/8 in.)

The surface of the wall is first plastered with lime mortar in the usual way, and then the tiles which should be kept immersed in water for at least an hour, are each covered with a paste of neat cement on the back, and laid flat against the wall surface true to line and plumb, and pressed with light strokes of a wooden mallet. Rounded angle tiles, suitable for inner or outer corner angles, and corner tiles, for corners where three surfaces meet, are available. The joints should be very close—as thin as paper.

Questions for Revision

(1) What is the object of plastering wall surfaces? Why is mortar of lime ground twice? Which kind of lime is good for plastering and why?

(2) What is the main difference in cement plaster and lime plaster? What is rendering?

(3) Write brief notes on:—(a) Floating course; (b) Neeru; (c) Rough cast or stucco plaster; (d) Acoustic plaster. (e) Depeter; (f) Guniting; (g) Washable distemper.

(4) What are plaster boards, and what advantages do they possess over ordinary plaster?

(5) What is the object of pointing joints?

(6) What is the difference between colour washing and distempering? What is oil-bound distemper?

ROOFS : 15

A ROOF is a framing with a covering above it, erected over the top of a building with a view to protecting the latter from the elements. The roof must, therefore, be designed and constructed to meet the requirements of different climates, and the covering materials available. For instance, in the plains where rainfall is meagre and heat intense, greater protection is required from the sun, and so a thick, flat roof is more suitable; whereas in coastal regions, where the temperature is more or less equable, but rainfall heavy, a pitched or sloping roof is desirable.

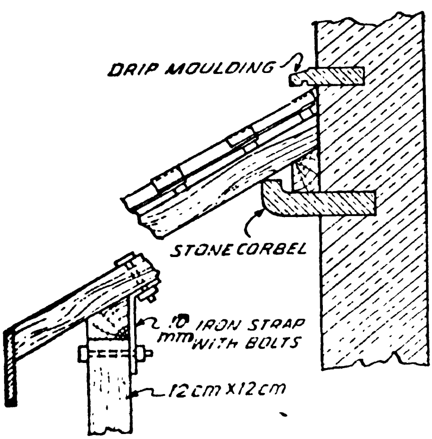


Fig. 573:
A Lean-to Roof.
Shows a stone template to rest wood plate upon and a drip moulding on top of roof.

Fig. 574:
On account of the inclination of the roof the posts are likely to be pushed out. To prevent this, an iron strap is bolted to a rafter and post together.

The main divisions of roofs are two, viz., (1) *Pitched, pent* or *sloping,* and (2) *Flat.*

We shall first discuss the pitched roof.

(1) **Pitched Roof:** In the evolution of the present day complicated roof, the *lean-to* verandah roof comes first as the simplest type. The upper end of the sloping rafters rests on a wooden wall plate placed on a wall or corbels projecting from a wall, and the

TABLE NO. 17
IRON STRAPS AND BOLTS FOR TEAKWOOD TRUSSES

Span m.	Connecting Principal and Tie-beam: Bolt Diam. mm.	Strap: Thick mm.	Strap: Wide mm.	Connecting Tie beam and King or Queen Post: Bolt Diam. mm.	Strap: Thick mm.	Strap: Wide mm.	Kind of Truss	Distance Between End of Strap and Bolt: Principal and Tie beam mm.	King-post and Tie-beam mm.	Fish-Plates and Bolts If Required: Fish-plates	Bolts
4	18	8	30	16	8	18	King Post	24	18	5 mm. plates, length equal to 10 times the depth of the beam, on both sides with bands clawed into timber.	25 mm. diam. 6 Nos. at 15 cm. intervals from the joint.
4.5	18	8	30	16	8	18	King Post	24	18		
5	18	8	40	16	8	24	King Post	24	18		
5.5	18	8	44	16	8	24	King Post	30	18		
6	18	8	44	16	8	24	King Post	30	18		
6.5	24	8	48	18	8	24	King Post	30	18		
7	24	8	48	18	8	24	King Post	30	18		
7.5	24	8	52	18	10	24	King Post	30	18		
8	24	8	56	18	10	26	King Post	40	18		
9	24	12	56	18	10	26	King Post	44	18		
10	24	12	60	18	10	28	King Post	44	18		
11	28	16	60	18	10	28	King Post	44	18		
12	28	16	62	22	12	30	Queen Post	50	24		
13	30	18	70	22	14	30	Queen Post	56	24		
14	30	18	70	24	16	40	Queen Post	56	24		
15	30	18	70	24	16	40	Queen Post	62	24		

The following are the roof slopes allowed in this country:

TABLE NO. 18
SLOPES OF ROOFS OF VARIOUS MATERIALS

Pantiles	7½ in 12
Country Tiles	7 in 12
Mangalore Pattern	1 in 2
Slates	5 in 12
Corrugated Iron or Trafford (Asbestos Cement) Sheets	1 in 4
Asphalt, Concrete, or Mud Terraces	1 in 24 to 36

A *Hipped Roof* is that formation of a roof at the end, in which it slopes down from the ridge to the top of the end wall,

which, in this case, is not raised but built to the same height as the side walls. (See Figs. 592, 593.) The downward sloping

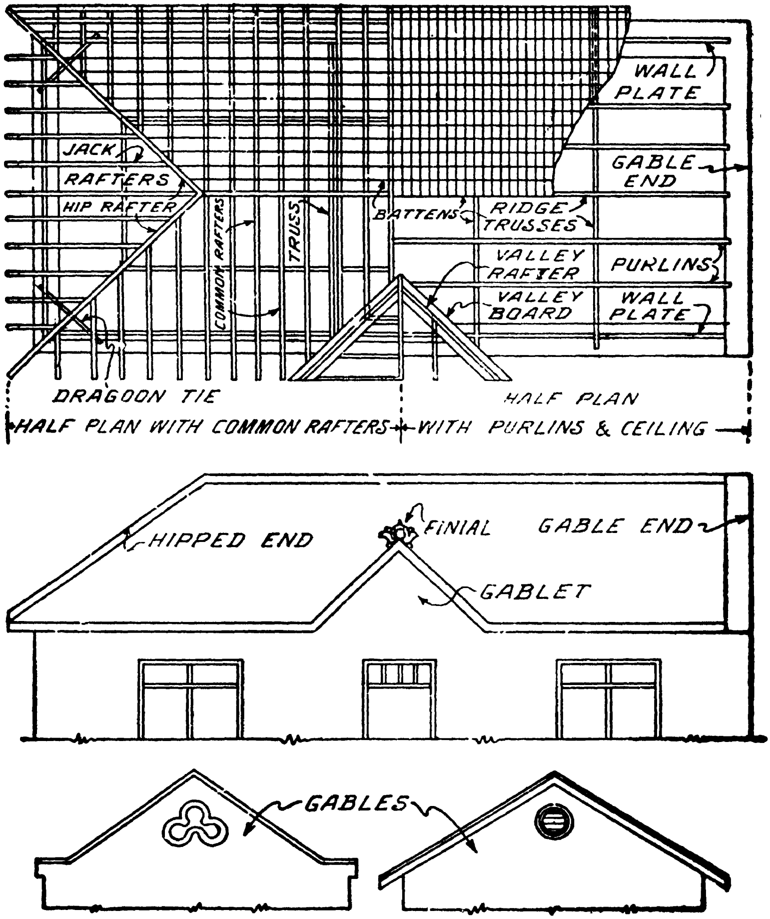


Fig. 592:
Plan of a roof showing the different parts with technical terms.
Fig. 593:
Front elevation.
Figs. 594, 595:
Elevations of a gable.

external angles forming ridges on the two edges of a hipped roof, are called hips. A hipped roof is supported on two hip rafters

3. Half round Country Tiles.
4. Mangalore or Similar Other Tiles.
5. Corrugated Iron or Asbestos Cement Sheets.
6. Slates.

1. *Thatch* is the cheapest and lightest material, but it is inflammable, absorbs moisture, rots and gives out a foul odour, harbours rats, and has to be renewed every few years as the bamboos are subject to attack of dry rot.

A pitch of 35° is usually sufficient. A framework, consisting of round bamboos laid 30 cm. (1 ft.) apart as rafters, and split bamboos laid longitudinally across them at 15 cm. (6 in.) intervals tied together by a coir or flax string, is first made, and a layer of long grass about 5 cm. (2 in.) thick is laid on it and sewn to the frame. A handful of grass is first taken and spread in a width of about 10 cm. (4 in.), the next handful is laid with an overlap of 5 cm. (2 in.), and so on. The frame is then placed in position on roof timbers and nailed to it. Two more layers of grass are then similarly laid, making a total thickness of 15 to 30 cm. (6 to 12 in.) It is finally trimmed in straight lines at the eaves.

2. *Flat Pan Tiles* and (3) *Half-round Country Tiles:* For these, common rafters are laid 22 to 30 cm. (9 to 12 in.) centres, and teak or sal battens 50 mm. × 12 mm. (2 × ½ in.) are nailed 6 cm. (2½ in.) apart. If round rafters are used, their upper surface should be brought in one sloping plane by planing projections and nailing suitable packing in the hollows. The tiles should be laid flat with sufficient overlap. The last row of tiles near the eaves is laid in lime or mud mortar, and is further firmly secured in position by an iron rod on its top, tied down to the battens below it.

Sometimes country tiles are laid in two layers, one over the other. This is called double tiled roof. This requires the roof timbers to be of greater strength than usual.

4. *Mangalore Tiles:* These are lighter than pan or country tiles, and require rafters below them at 45 cm. (1 ft. 6 in.) centre to centre. As their size is large, only cut wood rafters, are suitable.

For a Mangalore tiled roof laid on ceiling boards, rafters are sometimes omitted altogether. Boards are nailed directly on top of purlins, and the tiles are laid on battens nailed on the boards at 12½ in.* centres. Usually a coat of coal tar is applied

* 12½ in. to suit the size of tiles manufactured so far.

on the upper surface of the boards on which *khaddar* cloth dipped in coal tar is spread and stretched, and the battens are nailed on it. The lowest batten i. e. the one nearest to the eaves, should have double the ordinary thickness and should be nailed closer, i. e. at 25 cm. (10 in.) in the case of Mangalore tiles.

The ridge tiles are laid dry and pointed with cement mortar in preference to lime, as cement sets early, and watering, which is likely to be neglected at such a height, need not be attended to for more than 3 to 4 days.

Where, on account of high wind, Mangalore tiles, which are light, are likely to be blown away, the lowermost row, viz. at eaves, should be screwed down to the battens, or secured by wires through holes drilled in them.

The tiles in the portion overhanging the gable are also likely to be blown away by wind which first strikes the wall surface horizontally, or obliquely, and when obstructed, is directed upwards. The remedy is to provide a ceiling on the underside of the overhanging portion.

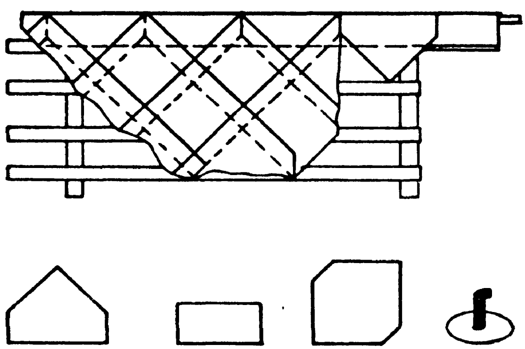
5. *Corrugated Iron Galvanised Sheets and Asbestos Cement Corrugated and Trafford Sheets:* As the sheets in both cases are light, purlins may be spaced at 1 to 1·25 m. (3 to 4 ft.) centres. The lengths of the sheets should be so adjusted that the joint comes on the top of a purlin. The minimum overlap should be four inches for lengthening and two inches or 1½ corrugations for widening. The holes for fixing the sheets should be made on the ridges and in the case of asbestos sheets they must be drilled, not punched. Galvanised screws of minimum 5 cm. (2 in.) length with lead or bitumen (reinforced with metal) should be used for fixing the C. I. sheets to wood work and G. I. bolts for joints on the overlap.

Asbestos cement sheets, suitable for roofing, are available in two varieties: (1) With corrugations, and (2) with wider channels. Though asbestos, which is a non conductor of heat, goes into their composition, on account of their thinness, heat is not mitigated. They are further breakable, and heavier, than C. I. sheets; but they look neater and cleaner and their colour, either grey or red, harmonizes better with the architecture than that of C. I. sheets.

6. *Slates:* Slate roofing is not used much in India as natural slates have to be imported from abroad. Where slate roofing

is sometimes used, e. g. on hill stations, they are bituminous slates known as *Eternit.*

Slates are smooth, hard, non absorbent, and heavy, requiring strong supporting timbers. The slabs are usually 40 cm. × 40 cm. (15¾" × 15¾")* in size (Fig. 600), and are fixed on battens 4 cm. × 2·5 cm. (1½"×1") nailed to rafters at 23 cm. (9¼") centres. The batterns at the eaves should be at 19.5 cm. (7¾"). The first row near the eaves should be of slabs 40 cm.×20 cm. (15¾" × 7¾") (Fig. 597), the second on the top of this, of triangular slabs, (Fig. 598), and the remaining rows above this should be of the standard slabs of 40 cm. × 40 cm. (15¾" × 15¾"). Slates are laid with an overlap of 7 cm. (2¾") The first two rows near the eaves are fixed with copper nails and the standard slabs by copper clamps, illustrated in Fig. 601, consisting of a disk and a pin. The disk is slipped under adjacent edges of two slabs, and through the corner of the slate above, and bent, binding the three slabs together.



Figs. 597—601:
A slate roof and different shapes of slates and the fixing disc and pin.

Flat Roofs: With the advent of very reliable water-proofing materials, flat roofs have been coming into greater prominence even in places where rainfall is heavy. There are two types: (1) Just a roofing slab with a reasonable slope on the top to drain off rain water, and (2) Terraced roof, designed and constructed for use as an out door living room.

At a slightly higher cost, the second type provides an extra accommodation which may be used for roof gardens, drying

*The present size of slate slabs is 15¾" × 15¾" or 40 cm. × 40 cm.

yards, playgrounds and even miniature golf courses. Even as an out door living room in domestic buildings, it is a great blessing in the tropics. The second advantage is that a building can more easily be made fire proof with a flat roof than with a sloping one. A third advantage claimed for flat roofs is that they keep the rooms below them cool; but this is doubtful as the thickness of such roofs is scarcely more than 15 cm. (6 in.). A fourth real advantage is that they simplify roof construction. A sloping roof, to cover an extensive area of a building consistent with economy, to provide for light and ventilation and architectural appearance, is not an easy problem. Besides, a complicated roof with a number of valley gutters is likely to leak, and is expensive to keep in good repair. One more advantage it possesses in days of modern warfare is that it is proof against incendiary bombs.

Against these advantages may be reckoned the following disadvantages:

1. On account of the extreme variation in temperature in this country, hair cracks are bound to occur on the surface which cause leaks.

2. A leak in a flat roof is very difficult to trace and set right, whereas one in a tiled roof without ceiling can be easily spotted.

3. A flat roof exposes the entire building to the elements, whereas the projecting eaves of a sloping roof tend to protect it.

4. A leaky, flat roof may prove a source of danger to a building with walls in mud mortar. Even in *pucca* buildings the timber rots and steel rusts. Besides, it makes the house damp, which is a positive danger to health.

However, all the above objections, except the third, are based on the assumption of unsound design or construction. With modern materials and progress in science, it is not difficult to make a perfectly water tight roof.

The cheapest and reasonably water tight roof can be made with mud, if good *white* earth, containing a large percentage of sodium salt, is available. Such roofs are extensively used where rainfall is light, as in the Punjab and Sind.

The roof consists of rolled steel beams of the necessary size, properly spaced according to the span. On top of these are placed T irons usually 50 mm. × 50 mm. × 6 mm. at 4·5 kg./m. (2″ × 2″ × ¼″ at 3·22 lb. per foot) spaced at 32 cm. (12½″), centre to centre, flange upwards. Between the flanges of these are

set well burnt tiles measuring 30 cm. × 30 cm. × 5 cm. (12″ × 12″ × 2″) or 30 cm. × 15 cm. × 5 cm. (12″ × 6″ × 2″) in lime mortar with joints carefully pointed. In the Punjab, a six inch layer of stiff mud is laid on this and beaten until quite hard. The top is finished with mud plaster in which cow dung is mixed, and the surface is finished with a wash of 4 parts of cow dung and one of cement mixed in water, evenly applied and wiped clean from the surface. This wash should be renewed from time to time. A slight slope, say 1 in 30, is given on the top.

In Sind, a layer of mud, 2·5 cm. (1 in.) thick, is laid on the tiles, then *bhan* 5 cm. (2″) thick, mud layer again 2·5 cm. (1″) and *bhan* 5 cm. (2″), and lastly plaster of mud 5 cm. (2″) thick is applied, and the roof is completed. A surface slope of 1 in 24 is given.

In M. P. and parts of the Maharashtra State, excellent mud roofs which do not leak and keep the building cool are made even though the rainfall is fairly high, viz., between 375 and 625 mm. (15 and 25 in.). On wooden bridging joists of suitable section placed 30 cm. (1′) apart, pieces of teak boards 4 cm. (1½″) thick selected from timber waste, are nailed. On these is spread a layer of about 3 cm. (1 in.) thick of wood shavings, then a layer of burnt bricks in mud laid on edge, and on the top of these a 10 cm. (4″) layer of stiff mud beaten well, and the topping is made with 3 cm. (1″) layer of loose white earth specially brought from old village sites now deserted, even from long distances, i. e. earth containing a fairly high proportion of sodium salts. A small surface slope is given. During the first rains, the roof might leak at a few places for a few minutes, but as soon as the loose earth enters the cracks, the leaks are automatically stopped. The layer of loose earth has to be renewed once in a year or two before the rains.

If instead of wooden joists and boarding, an R. C. C. slab or brick jack arch roof is made, and layers of mud and loose earth are laid on it, a perfectly leak proof and cool roof will be formed.

Another excellent way of making a water tight flat roof is: Lay on the top of the floor, constructed in one of the ways described in the chapter on flooring supported on walls, except those in which timber is used, about 10 cm. (4 in.) brick bat concrete, consisting of three parts of brick bats, one part of gravel and sand, and 50 per cent by volume of lime mortar, and ram it hard

for three days with frequent wetting with water. Then lay on its top a china mosaic floor, or for that matter, flat pieces of any non absorbent, hard material, as described in the chapter on Paving on Ground Floor. The latter, if not having an even polished surface like pieces of glazed china tiles, may require to be polished.

The success of the above floor in respect of prevention of heat, cold and moisture, lies in several facts: (1) The total thickness of the floor is considerable—about 25 cm. (9″) or more, hence, the effect of heat and cold to which the surface is exposed, does not reach the inner depth. (2) Since there are innumerable joints on the surface, the movements due to expansion by heat or contraction by cold are distributed and diminished. (3) The large percentage of mortar in the concrete makes the mass non-porous and (4) The polished surface at top reflects the heat rays away.

A perfectly non leaky flat roof surface can be made by using mastic asphalt in a layer of 18 to 25 mm. (¾ to 1 in.) thick on a flat sub grade of R. C. C., jack-arched, or any other sort of floor. The process has been described under Paving on Ground Floor. The colour of asphalt, which is black or grey, is objectionable to some people when the terrace is used as an outdoor living-room; but coloured asphalts are now available to overcome this objection. However, an asphalted surface absorbs heat and radiates it very slowly at night which is a great disadvantage in the

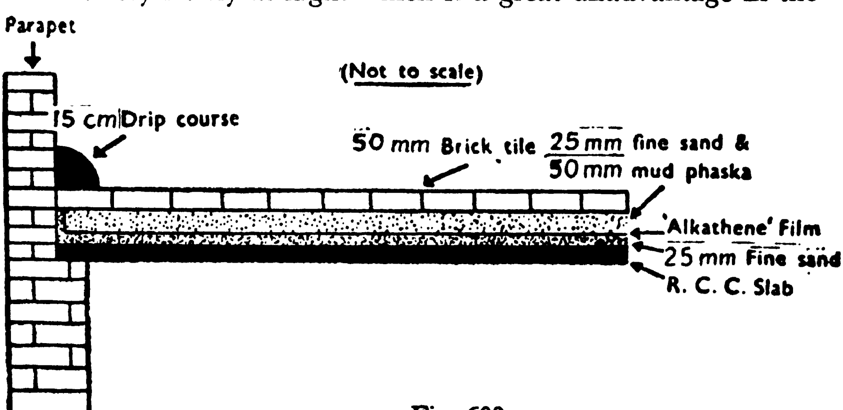


Fig. 602.

tropics. Otherwise, as the material is resilient, it forms one of the best floors, where a hard wearing, sanitary, impervious, and particularly quiet surface is a special consideration.

The latest advance in making flat roofs perfectly water-tight is by the use of a plastic transparent film known by the trade names of "Alkathene" or "Polythene", available in thicknesses from ·001 to ·007 in. (100 to 700 gauge) in rolls 1·8 m. (72 in.) wide. The method of application is to add the following layers on top of R.C.C. slab: (i) 25 mm. (1″) fine sand, (ii) plastic film with 8 cm. (3 in.) overlapped joints, (iii) 3 cm. (one in.) fine sand, (iv) 5 cm. mud *phaska* (clay mixed with shredded straw), and when this is dried, (v) 5 cm. (2 in.) brick tiles or thin flagstones in mortar as shown in Fig. 602.

In all the above types of floors all corners should be rounded and the surface water proofing layer used should be carried to a height of at least 15 cm. (6″) on the surface of parapet walls and joined there to the plaster. A good surface slope of from 1 in 20 to 1 in 40, depending upon the intensity of rain fall of the place, should be given, and sufficiently large rain water spouts, or down take pipes, provided to drain off rain water before it gets a chance to accumulate.

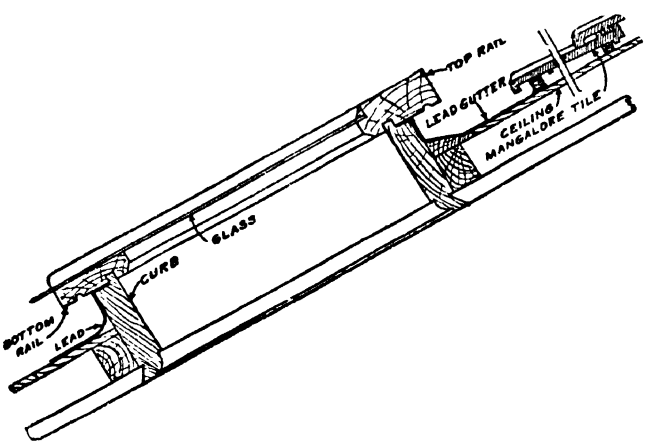


Fig. 603:
A skylight, showing its different parts.

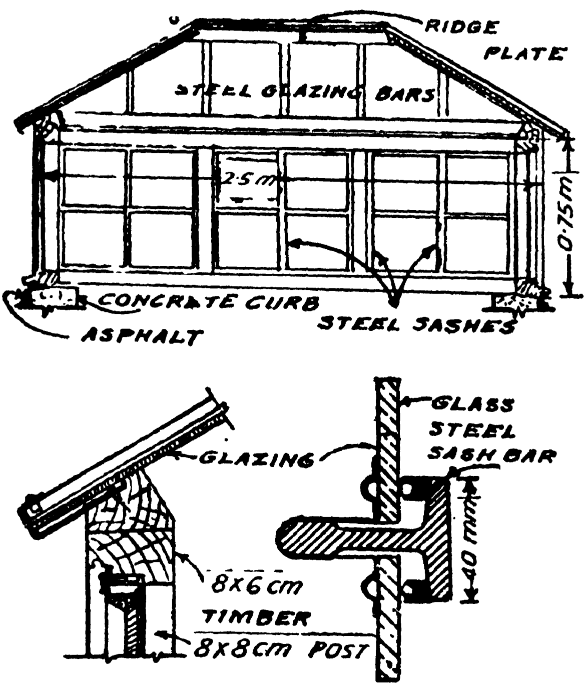
With flat roofs it is a simple matter to admit direct or diffused light into rooms below through lanterns, skylights, or by introducing *pressed glass* or *Glass-crete* blocks commonly used for pavement lights. (See Figs. 513 to 515.)

Skylights and Lanterns: These are used to admit light from

the top in the apartments where it cannot be taken for some reason or other from side walls.

A skylight is generally flat, and is fitted on a pitched roof, parallel to its inclination, whereas, a lantern is usually much bigger, has vertical sides, and is fixed on the top of a flat roof. A lantern may have shutters like those of a window, and in that case it can be used also for ventilation.

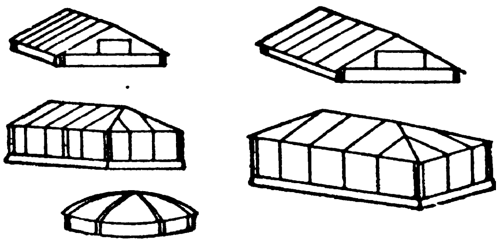
Where Mangalore tiles are used for roof covering, glass tiles, identical in shape and size to Mangalore tiles, manufactured by Messrs. Ogale Glass Works, Ltd., can be substituted very conveniently at a few places for Mangalore tiles, and they serve as excellent simple skylights at a low cost.



Figs. 604—606:
Lantern light and its details.

For fixing a skylight, the roof rafters are trimmed, leaving between them a space to suit the size of the skylight frame. Then wooden curbs 22 cm. × 4 to 5 cm. (9″ × 1½″ to 2″) are fixed one edge between the sides of the rafters, and the skylight frame

is fixed on top of them. The projecting top of the frame should be throated, and lead flashings provided on all sides. On the upper side, a gutter is required to be formed for diverting the rain-water from the tiles above the skylight toward the sides. Fig. 603 shows a section of a skylight. Steel skylights complete with frame and metal sash bars are available.



Figs. 607—611:
Five different forms of lantern lights.

Fig. 604 shows a section of a lantern in which a metal frame and sash bars are used. Fig. 605 shows a large scale vertical section of a lantern at the eaves, and Fig. 606 a large scale section of a steel sash bar.

Figs. 607—611 show different forms of lantern lights, small and large, fixed in a flat roof.

Steel roof trusses and their connections are discussed in the chapter on Structural Steel.

Questions for Revision

(1) Discuss the *pros* and *cons* of a pitched roof *versus* a flat roof.
(2) Describe the evolution of a king-post truss from the simple lean-to roof with sketches.
(3) Define the following terms:
Drip moulding; Template; Gib and cotters; Scissors truss; Straining sill; Gable; Jack rafter; Barge board.
(4) What are the common roof slopes adopted in this country for the following roofing materials:
(a) Country tiles; (b) Mangalore or Allahabad tiles; (c) G. C. I. sheets; (d) Flat terraced roof.
(5) Describe any one method of constructing terraced mud roof with which you are familiar.
(6) What is the difference between a skylight and a lantern roof light?
(7) What are the precautions required to prevent tiles on a roof being blown away by wind?

CEMENT CONCRETE, PLAIN AND REINFORCED : 16

Definition: Concrete is an artificial stone composed of cement and water, as the active constituents, and aggregates, coarse and fine, as the inert substances.

Cement: Though there are different kinds of cements manufactured, such as the ordinary or the normal setting cement, quick setting cement, rapid-hardening cement, low-heat cement, high-alumina cement and coloured cement, the cement most commonly used in building construction is the ordinary or normal-setting cement. Occasionally, rapid hardening cement is used when the work is to be done quickly, or forms are to be soon stripped and used elsewhere; and coloured cements are used for decorative effect in the finishing of the building.

Ordinary cement is sold in jute or paper bags weighing 50 kg. (one cwt. gross), or 20 bags to a tonne (ton). For purposes of calculations, 1000 $cm.^3$ (one cu. ft.) of cement should be taken to occupy 35 lit. or each bag to contain 50 kg. (one cwt.) (1·2 cu. ft.) of cement.

Rapid hardening cement is supplied in jute bags lined with water proof paper, weighing 50 kg. (one cwt.) gross, but as it is ground finer than ordinary cement, each 50 kg. (one cwt.) bag contains 41 lit. (1·4 cu. ft.)

Storage of Cement: Cement must be kept in a dry place, preferably on a platform about 15 cm. (6 in.) above the ground level, and away from walls, and protected from every source of moisture to prevent its deterioration.

Sampling Cement: Cement should be taken from the centre of twelve bags selected at random and should be packed in airtight tins. If this is not possible, great care must be taken to see that the cement is not packed in proximity to samples of damp sand or aggregates.

The minimum quantity for a sample depends on the details of test necessary, and usually a sample of 2 lbs. is sufficient for ascertaining their suitability as regards setting quality, soundness and adulteration.

TABLE NO. 19

Tests of Cement

Property	Ordinary Portland (I.S.269-'58)	Rapid-hardening Portland (I.S.269-'58)	Portland Blast Furnace Slag (I.S.455-'62)
1. Fineness of Grinding Maximum residue by weight on I. S. sieve No. 9 (%)	10	5	10
Minimum specific surface by air permeability method (cm./gm.)	2,250	3,250	2,250
2. Setting time (Minutes) Initial Final	 More than 30 Less than 600	 More than 30 Less than 600	 More than 30 Less than 600
3. Minimum tensile strength of 1:3 cement-sand briquettes (kg./cm.²) At 1 day At 3 days At 7 days	 — 20 25	 20 30 —	 — 20 25
4. Minimum compressive strength of 1:3 cement-sand mortar cubes (kg./cm.²) At 1 day At 3 days At 7 days	 — 115 175	 115 210 —	 — 115 175
5. Soundness by Le Chatelier method. Maximum expansion after boiling cement paste for 3 hours (mm.)	10	10	10

Tests of Cement: Table No. 19 gives the tests of cement according to the latest Indian Standards Institution's Specifications.

Sampling of Water: In sampling running water, a true sample can be obtained only by taking the same at various periods throughout the day. In wide and deep rivers it may be necessary to take them at various points across the stream and in the depth.

Water: The water to be used for concrete should be clean, free from any organic impurities, acids, alkalies, greasy or oily substances, either in suspension or solution.

Water is as important a part of concrete as cement or aggregate. The function of water in the mixture is threefold.

(i) First, to wet the aggregate. More water is required to wet a given weight of aggregate consisting of small particles than to wet the same weight of another aggregate composed of larger particles, because the total sum of the surface areas of the greater number of particles in the former is larger than that of the latter.

(ii) After the demand for wetting of aggregate is satisfied, water is required to act as a lubricant for the aggregate and cement. The latter it does in three distinct operations: (a) Coating the surface of the particles of aggregates, (b) Filling the space between the particles, and (c) Making the mixture flow into moulds. The consistency of the concrete depends upon this quantity of water.

(iii) Later, part of the water *combines chemically with the cement* to form a hardened paste, or binding medium, for the pieces of aggregate. This water goes to supply the water of crystallization, and plays an active part in contributing to the strength of the concrete.

The necessary quantity of water required for (i) and (iii) is automatically taken up by the concrete. The supply for (ii) may vary, and this determines the consistency. The less the quantity of water used for this, the more closely will the particles knit together, making the concrete stronger and denser. Any extra water beyond the minimum required for the above purposes tends to dilute the cement, which flows away from the interstices, and the result is that the strength of the concrete is reduced. It is, therefore, important to keep the amount of water used in mixing to a minimum, consistent with workability, if the strength is the principal desideratum. The ratio of the volume of mixing water to the volume of cement is called the *Water-Cement ratio.*

TABLE NO. 20

Relation between Water-cement Ratio and Strength of Concrete

Water-cement Ratio			Crushing Strength kg/cm.^{2} at 7 days	
Lit./50 kg.	By weight	By volume		
18	.36	.52	392	Mix too dry for hand compaction
20	.40	.58	345	
22.5	.45	.64	300	
24	.49	.71	262	
27.5	.55	.77	230	Mix workable for hand compaction
29	.58	.83	200	
31	.63	.90	168	
33.5	.67	.96	150	
35.5	.71	1.03	130	
38	.76	1.10	117	Wet mix
40	.80	1.16	105	

TABLE NO. 21

Water-cement Ratio and Cube Strength

Water-cement Ratio by weight	Cube Strength kg./cm.^{2}	
	At 7 days	At 28 days
0.35	400	525
0 40	350	470
0.45	300	420
0.50	250	370
0.55	220	330
0.60	180	280
0 65	155	245
0.70	135	220
0.75	112	200
0.80	105	175

Workability depends on (a) Shape of the aggregate (rounded or cubical particles gives better workability; (b) Grading, (c) Proportions of aggregates, (d) Efficiency of mixing, (e) Quantity of cement and (f) Quantity of water.

If the maximum strength is desired and for that the specified quantity of water does not give the desired workability,

(i) The proportion of coarse aggregate may be reduced. This, however, will increase the cost of concrete, or,

(ii) The proportion of coarse aggregate may be reduced and a corresponding increase made in that of the finer aggregate, or,

(iii) The concrete should be mixed once more, or, better still, a vibrator (described later) should be used, or,

(iv) More water, and with it also more cement, should be added; in other words, the cement-water ratio should be maintained high.

Tables 20 and 21 (p. 285) are typical of the relation between crushing strength of concrete and the cement-water ratio (both by weight and volume) in the mixture.

Test for Consistency of Concrete (Slump Test): *Apparatus*—A mould in the form of a frustrum of a cone open at ends with top diameter 10 cm. (4″) and bottom 20 cm. (8″) and height 30 cm. (12″); a rod 60 cm. (2 ft) long, 16 mm. (5/8″) diam., bullet pointed at one end. (See Fig. 613.)

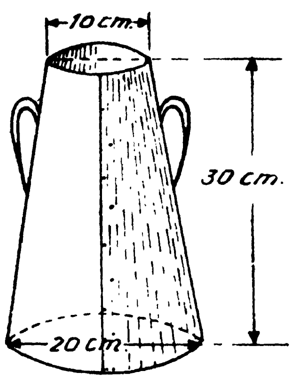


Fig. 613:
Apparatus for slump test.

Place the mould on a flat, non absorbent surface and fill it to about a quarter of its height with the sample of concrete, then tamp it with the bullet point of the rod 25 times. Fill the mould completely and strike off the top. Then remove the mould by slowly raising it vertically immediately after filling. The moulded concrete will slump or subside to a certain extent. Measure the height of the specimen in mm. (in.) The consistency is recorded in terms of mm. (in.) of subsidence, which is known as the *slump*. The following values of slump are generally adopted:

TABLE NO. 22

	mm.		mm.
Concrete for road construction	19	to	38
Slabs	25	to	50
Normal reinforced concrete work	50	to	150 (Max.)
Thin vertical sections of columns and thin confined horizontal sections	100	to	175
Vibrated concrete	12	to	25

For thin R. C. C. partition walls (4 to 5 cm. or 1½″ to 2″), ornamental *jali* work, etc., and in situations where concrete has to be poured through chutes, a wet consistency (slump about 225 to 250 mm. or 9 to 10 in.) may be required. If greater strength is desired here, more cement should be used. This means, in other words, increasing the cement water ratio.

Aggregates : The material used for aggregates, whether coarse or fine, should be of chemically inert mineral particles, strong, hard, durable, non absorbent, free from soft, friable, flat flaky, porous, elongated, or laminated particles, also free from clay, organic matter, soluble sulphates and all other matter likely to retard the setting of the cement, reduce the strength of the concrete, or corrode the reinforcement. The coating of such substances as clay, dust, oil, etc., on the surface may prevent a bond of the interlocking crystals formed during the process of the setting of the cement.

The presence of organic matter may interfere with the chemical reaction and may also seriously affect the hardening of the cement.

Aggregates usually employed for making concrete, are: Sand, gravel, shingle, crushed stone, broken brick, *kunker*, furnace slag, and coke breeze.

For R. C. C. work, sand, gravel, shingle and crushed rock only should be used, broken brick and blast furnace slag, if hard, and *kunker* may do for plain concrete. The latter makes a porous concrete in which the steel may rust.

The shape of aggregate has an important bearing on the workability of concrete. Pieces approaching cubical or spherical shape give a better workability than thin, elongated, angular ones. Rounded particles make concrete more workable, but angular

ones interlock better with each other. The surface should be rough. A smooth, glossy surface does not make a good bond with cement paste.

Aggregates for fire resisting concrete should be of a refractory nature, with a low thermal conductivity and low coefficient of expansion. Aggregate of limestone is very bad in this respect. When heated and quenched by water, used for extinguishing fire, it falls to powder. Overburnt broken brick and blast furnace slag are good materials from this point of view.

Sand or *Gravel,* particularly that obtained from a deep river with a sluggish flow, is likely to contain silt and clay in the form of an adherent coating on the particles. It should, therefore, never be used without being washed if the concrete is to be reinforced with steel. Gravel usually contains less voids than crushed stone and also makes a more impermeable concrete. Sea sand and gravel are also likely to contain salts and must be washed for R. C. C. work.

Stone Metal of granite, gneiss, close grained sandstone, trap, hard crystalline limestone, and such other hard rocks, is satisfactory. If broken in a crusher, it may be accompanied by considerable crusher dust, which is harmful.

Broken Brick Aggregate: Broken brick is, really speaking, not a suitable material at all for either plain or reinforced concrete. In plain concrete it affects the compressive strength of the concrete, and in R. C. C., air and moisture may reach the steel reinforcement through its pores and cause it to rust. It must, therefore, be used as a last resource when no stone or gravel aggregate is obtainable. In that event, it should be obtained from good, hard, rather overburnt than underburnt bricks, and should be free from brick dust.

Slag, Coke Breeze, Coal Ashes, etc.: These are all inferior sorts of materials and are used in places where much strength is not required. Selected broken blast furnace slag may produce tolerably good concrete. Still, corrosion of reinforcing steel may occur in it. Boiler slag and coal ashes are likely to contain sulphur in some form, which is harmful to concrete.

Coarse Aggregates are generally regarded as those aggregates which consist of particles all retained on I. S. Sieve No. 480 (3/16 in. sieve), and should have all the sizes between this and the maximum specified limit. For R. C. C. the maximum limit is

usually 20 mm. (¾ in.), though 25 mm. (1 in.) size is often allowed. For plain concrete, it may go up to 62·5 mm. (2½″) or even larger.

Fine Aggregates will pass through a I. S. Sieve No. 480 (3/16″ sieve) but should contain not more than 1 to 8% of fine particles, which will pass through I. S. Sieve No. 15 (No. 100 B. S. sieve), according to the purpose for which the concrete is made.

Fine aggregate mostly in use is natural sand having rounded particles, as it is relatively plentiful and cheap, but screenings from a stone crusher, having angular particles may also be used as fine aggregate. The latter may contain a large proportion of stone dust, which must be removed by screening. The round particles of sand make a smoother working mortar or concrete than do screenings from a crusher, which are sharp and angular. River sands in India, even though they may appear perfectly clean, may contain an excessive proportion of clay and silt. It is, therefore, desirable to wash such sands before use for first class work. If these impurities are not removed,

(a) They work to the surface during spading and trowelling of fresh concrete, causing later, hair cracks due to shrinkage.

(b) They require extra mixing water which drowns the cement.

(c) They interfere with the bond between aggregate particles and cement paste, by forming a film on the surface of aggregate which separates the two.

The result is to reduce the strength of the concrete and also cause seepage difficulties.

The total amount of silt, clay and loam together contained in sand should not exceed 5%.

Besides clay, silt, and loam, river sand, and especially sea-beach sand, are likely to contain another impurity in the form of decayed vegetable or organic matter, which is even more serious than silt and clay, because it prevents the cements from hardening properly, if at all. It is not apparent to the eye and may occur in a seemingly clean sand. For its detection a chemical test must be applied as described below:

Test on Fine Aggregate :

(a) *Test for the Presence of Clay and Silt:* Take a representative sample of sand by the method of quartering,* sufficiently moist to prevent segregation, sufficient in quantity to yield about 500 grams when dried. Dry it at a temperature not exceeding 110° C. (230° F.).

Put the dried material into a large pan and add water sufficient to cover the sand. Shake the contents vigorously for half a minute and allow them to settle for fifteen seconds. After this, pour off the water through a B. S. No. 200 mesh sieve. Repeat this, i. e., adding water, stirring, and pouring off through the sieve several times until the water poured is clear. Put the particles collected from the top of the sieve into the washed sand. Dry the latter at a temperature not exceeding 110° C. (230° F.) and weigh it. Then,

Percentage of impurities in the form of silt, sand, etc.

$$= \frac{\text{Original dry weight minus weight after washing and drying} \times 100}{\text{Original dry weight}}$$

(b) *Test for Organic Impurities :* Take a glass bottle of 225 to 280 cc. (8 to 10 ozs.) capacity. Fill nearly 1/3 of it with the representative sample of sand obtained by quartering. Add to it a 3% solution of sodium hydroxide (caustic soda) in water, till nearly 2/3rds of the bottle is filled. Put the stopper in and shake it vigorously, after which stow it away for twentyfour hours. If the liquid turns brown, the sand contains too much organic matter and should not be used without washing. If the liquid remains clear, or light straw-coloured, the sand may be regarded as satisfactory.

This is not a quantitative test, but one for detection of the presence of injurious *organic* matter just to serve as a warning.

Measurement of Materials : For proportioning aggregates to make a dense concrete and for mixing them with cement,

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* The method of quartering is as follows:

Take a basketful of representative sample of sand. Spread it out in a layer 8 to 10 cm. (3 to 4 in.) thick on a flat, clean ground or paved surface. Divide it into quarters. Reject two opposite quarters. Mix the remaining two quarters, spread, divide into quarters, and repeat the process until the two quarters remaining weigh 0.5 to 2 kg. (1 to 5 lbs.) according to the requirements of the test to be carried out. This is the sample to be used in tests.

quantities have first to be measured according to certain standards. These measurements present certain difficulties which will be first considered.

Measurement of Cement: Cement is often measured by volume, but this is a wrong practice and open to serious objection. If it is loosely filled in the gauge box, it may weigh only 70 lbs. per c. ft. and if it is tamped while being filled, one cubic foot of it may weigh more than 100 lbs. although its normal weight per c. ft. is taken to be 90 lbs. only. The only safe way of measuring cement, therefore, is by weight, either by actual weighing or taking the 112 lb. bag as the unit of each batch, considering its volumetric measurement as 1¼ cu. ft.

Measurement of Sand: This presents another difficulty if the sand is slightly wet, which is its normal condition.

Take a cubic meter (foot) measure and fill it with perfectly dry, fine sand. Remove the sand and mix 5% of water by weight with it and refill the measure. It will be found that all the sand will not go into it, but a considerable quantity will be left over. The explanation is that when the sand is moistened, every indivi-

TABLE NO. 23

BULKING OF SAND FOR VARIOUS MOISTURE CONTENTS

Moisture % by wt.	Fine sand	Medium sand	Coarse sand
1	16	8	6
2	26	16	12
3	32	22	15
4	36	27	17
5	38	29	18
6	37	28	18
8	35	26	16
10	32	22	12
12	28	19	8
15	22	12	2
17	20	7	0
20	9	0	0
27	0	0	0

dual particle of it is surrounded by a film of water which tends to hold the surrounding particles apart. The result is an increase in volume. This phenomenon is called the *bulking of sand.*

As a further experiment, if water is poured into the measure filled with damp sand till a film of water rises above the surface of the sand, it will be found that the sand has sunk down and the measure will accommodate all the sand which was previously left over after filling the measure with damp sand.

This shows that when sand is saturated with water, it occupies the same volume as that of dry sand.

The figures in the Table No. 23 give typical results of an experiment on bulking made with fine river sand.

The finer the aggregate, the greater is the bulking.

This bulking affects the proportioning of aggregates volumetrically to a very large extent. For example, if a proportion of 1:2:4 of cement, sand, and coarse aggregate is specified and we adopt one bag of cement equivalent to 35 lit. (1·25 c. ft.), then if the sand were dry the proportioning by volume of aggregate would be one bag cement: 70 lit. (2·5 c. ft.) sand: 140 lit. (5 c. ft.) coarse aggregate. But if the sand contained 8% moisture, the proportions would be one bag cement: 68 lit. sand: 140 lit. coarse aggregate (one bag cement: 1·7 c. ft. sand : 5 c. ft. coarse aggregate.)

Thus if the original proportions were maintained, the mixture would be rich and the concrete unnecessarily costly.

Measurement of Coarse Aggregate: This offers no difficulty in measurement either by volume or weight, as no bulking occurs in practice. Still, if it is wet, it must be holding some water, and allowance for this water, as well as that contained in sand, must be made while determining the quantity of water to be used in the mixture, and this aspect of the problem offers considerable difficulty.

It is very easy to measure water either by weight or volume. It will be seen, therefore, that measuring all the materials by weight is the only satisfactory method and is not affected even by the bulking of sand. However, it entails so much cost for the necessary apparatus and loss of time, that except, perhaps on big works like mass concrete dams, volumetric measurement of aggregates, based on batching with a cement bag as a unit, has, with all its faults, been found more practicable.

Proportioning of Materials: The principles involved in designing the correct mix are:

(1) The resulting concrete should possess the necessary strength required for the particular purpose for which the concrete is to be made, consistent with economy. As cement is the costliest, and at the same time, the only binding material of the ingredients of concrete, this means that there should be just enough cement in the mix to develop the necessary strength.

(2) After the quantity or proportion per cu. ft. of the mix is decided, the quantity of water should be determined according to that water cement ratio, which gives the best result in respect of strength, consistent with the workability of the mix.

(3) Next, adopt such proportions of the coarse and fine aggregates as will produce a workable mix with the water cement ratio already determined. The concrete which has the minimum

TABLE NO. 24*
APPROXIMATE MIXES FOR CONCRETE

Kind of work	Consistency	Maximum Size of Aggregate mm.	Nominal Mix Loose Volume	Total Water per Bag of Cement litres
Small precast work, posts, sills, lintels, very thin sections	Soft	10 to 12	1 : 2 : 2	22.5
Tanks, troughs, cisterns, watertight work	Medium	20 to 24	1 : 2 : 3	24.75
Foundations, basement walls, retaining walls, etc.	Medium or slightly stiff	36	1 : 2½ : 3½	29.25
R. C. work protected, upper floors, beams, columns	Medium or soft	18 to 24	1 : 2½ : 3½	22.5 to 24.75

Note:—The figures in the last column are of total water, which includes the water absorbed by the coarse aggregate, and free water held in interstices between particles of sand, for which allowance must be made, as shown in the following tables:

TABLE NO. 25*
APPROXIMATE QUANTITY OF FREE WATER IN SAND

Condition of Aggregate	Water in Gallons per cu. ft.	Water in Lit es/m.[3]
Freshly washed sand (very wet)	0.6 to 0.8	100 to 120
Moderately wet sand	0.4 to 0.45	about 60
Moist sand	0.2 to 0.25	" 30
Moist gravel or crushed stone	0.2 to 0.25	" 30

TABLE NO. 26*
APPROXIMATE ABSORPTION OF WATER BY EXTREMELY DRY AGGREGATES

Kind of Aggregate	Percentage Absorption by Weight
Sand	1.0
Pebbles, crushed limestone	1.9
Trap rock, granite	0.5
Porous sandstone	7.0
Very light and porous aggregate, such as broken brick, furnace slag, etc.	25.0

* By courtesy of the Concrete Association of India.

voids, is the densest and the strongest, and this can be accomplished by adjusting the proportion of the coarse to the fine aggregate to leave minimum voids.

In other words:

(a) Take minimum sufficient cement.

(b) Use just enough water, and no more.

(c) Balance the coarse aggregate and sand to make a workable mix.

Table No. 24 gives approximate proportions of materials in concrete required for different purposes.

The proportions of coarse to fine aggregates are determined by one of the following methods:

(1) Sieve Analysis. (2) Minimum Voids. (3) Arbitrary Standards. (4) Trial Mixtures.

Out of these, the first viz., Sieve Analysis is accepted as the standard method since it is the most reliable.

(i) *Sieve Analysis:* For this, representative test-samples of both coarse and fine aggregates are obtained by the method of quartering, already explained. These are then passed through a set of nine standard sieves. A complete set of sieves is given in the following table.

TABLE NO. 27.

BRITISH AND INDIAN STANDARD SIEVES FOR FINENESS MODULUS

Old B. S. Sieve No.	New I. S. Sieve No.	Nearest Fractional equivalent (inch)
3/16"	480 No.	3/16
3/8"	10 mm.	3/8
½"	12 mm.	½
¾"	20 mm.	¾
1½"	40 mm.	1½
2½"	63 mm.	2½
3"	80 mm.	3
No. 7	240 No.	1/10
No. 14	120 No.	1/21
No. 25	60 No.	1/42
No. 52	30 No.	1/84
No. 100	15 No.	1/168

The sample should not be less than:

(a) Fine aggregate: 1·5 kg. (3 lbs.)

(b) Coarse aggregate: 5 kg. (10 lbs.)

(c) Combined: 6·5 kg. (15 lbs.)

It should be dried to constant weight at a temperature not exceeding 110°C. (230°F.)

The sample is then separated into a series of sizes by passing it through the above sieves, and the percentage by weight of the residue on each sieve is recorded as shown in the Fineness Modulus Table No. 28 below.

Fineness Modulus of Fine Aggregates: 2·92.

Fineness Modulus of Coarse Aggregates: 6·66.

The above results, when plotted, give curves as shown in Fig. 614. The curve,

(a) Shows graphically the relative sizes of particles.

(b) Indicates what size particles are needed to make the mixture of fine and coarse aggregates to approach perfection.

TABLE NO. 28
FINENESS MODULUS OF COARSE AND FINE AGGREGATES

B.S. Sieve No.	I.S. Sieve No.	Weight of Sample 1000 grm.	
		Percentage Amount of Fine Aggregate Retained on each Sieve	Percentage Amount of Coarse Aggregate Retained on each Sieve
1½ in.	40 mm.	—	4
¾	20 mm.	—	14
⅜	10 mm.	—	58
3/16	480 No.	4	90
No. 7	240 No.	18	100
No. 14	120 No.	28	100
No. 25	60 No.	53	100
No. 52	30 No.	89	100
No. 100	15 No.	100	100
		292	666

(c) Affords a measure of determining the best proportions of different sands and coarse aggregates.

The ideal maximum density curve is a parabola, being a combination of a curve approaching an ellipse for the sand and a tangent straight line for the coarse aggregate.

This method is valuable not only as a means to determine the best proportions in which the two aggregates should be mixed, but also to show how the mixture may be improved by increasing or reducing the proportions of some particular size aggregate.

The method and the apparatus required are described in detail in B.S.S. No. 812 (1938).

(ii) *Proportioning by Minimum Voids:* In this method, the voids in the coarse and fine aggregate are separately determined, and sufficient sand is provided to fill the voids in the coarse aggregate and sufficient cement to fill the voids in the sand. The voids can be determined in either of the two ways: (1) Place the sample in a graduated glass and pour measured quantity of water till the interstices in the sample are filled. The quantity of water required determines the space occupied by the voids. This is, however, a rough measurement, since the air entrapped between particles and the moisture absorbed by the aggregate may affect the result. (2) The more correct is the method of

determining the voids from the known specific gravity of the material and the weight of the unit volume of the aggregates.

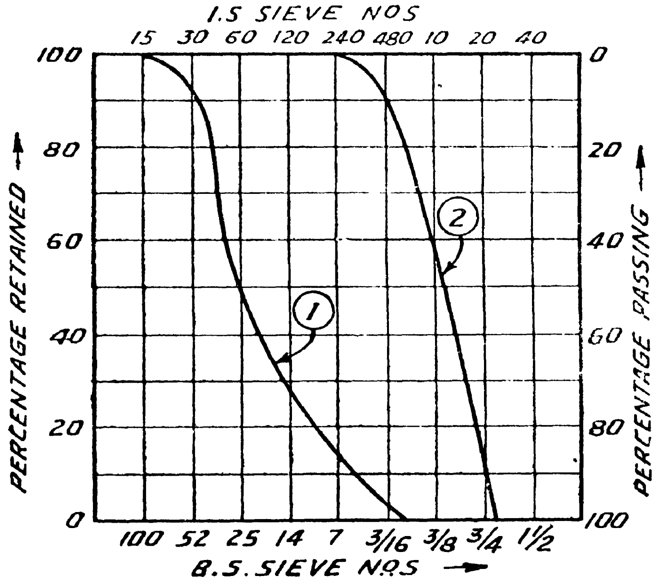


Fig. 614:
Graph. (1) River sand. (2) Crushed stone.

The results obtained by this method of proportioning by voids are not correct. First of all, the theory is wrong, for, the cement paste, covering the particles of sand, virtually increases their size, and thereby tends to increase the voids. The same must also be happening inside sand particles on account of the surface tension of water in the cement paste. Secondly, the percentage of voids in the aggregate varies with compactness, and the latter depends upon the different methods of handling and compacting. Thirdly, the moisture content of sand is not constant. Small variations in it may considerably affect the results by variation in bulking.

(iii) *Proportioning by Arbitrary Standards:* In this time-honoured method, one cubic foot of cement is taken as the unit of measurement, and coarse and fine aggregates are arbitrarily taken and the amount of water is determined according to the desired workability. In fact, workability is the real criterion. In this method the coarse and fine aggregates are generally taken

in the proportions of 2:1 as in the standard proportion of 1:2:4 or other proportions like 1:2½:5, 1:1½:3, or generally 1:*n*:2*n* So long as the aggregates are properly graded and consistency is more or less correct, the results are not far wrong.

(iv) *Proportioning by Trial Mixtures:* This method consists in placing a certain weight of coarse aggregate, sand, cement, and water, into a cylindrical vessel, tamping the concrete and noting the height of the upper surface. The cylinder is then emptied, washed, and used in the same manner for different mixes. A number of trials of successive mixtures are made and the mixture that gives the least volume for the same weight, i.e. one which is the densest, is adopted.

Mixing Concrete: If mixing is done properly, the strength of concrete is high. Because the various sizes of particles are evenly distributed, coating of dirt on the surface of particles is scoured off by the rubbing action, and the cement paste is evenly applied all round the particles.

Mixing is done very satisfactorily by machine. Machine mixers are of two types:

(a) Tilting Drum Type.
(b) Closed Drum Type.

In the former, materials are fed when the drum is in an inclined position facing the hopper. After rotating for a while, the concrete is discharged by tilting the drum on the opposite side. In the latter type the drum remains rotating in the same position, and the hopper tilts to receive the feed. After mixing is done, the concrete is discharged from the drum by operating a spout on the other side of the mixer. The mixing in the machine should be done for 1½ to 2 minutes, depending upon the speed of the mixer.

In hand mixing, the sand and cement should first be mixed in a dry state, and turned over at least twice, then the coarse aggregate added to it and turned over twice. Water, in quantities pre-determined per bag of cement, should then be sprinkled by the hose of a can and the mixture turned over 2 or 3 times.

Placing and Consolidating Concrete: The process of mixing and conveying to the site for placing should not take more than 40 minutes from the time water is first added. The concrete should be deposited into moulds and rodded so that it is

forced round the corners, edges, and round and between the reinforcing bars.

If the depth of the concrete is greater than a few inches, water is likely to collect at the top. This is called *laitance,* which becomes soft and chalky when hardened. To prevent this, a stiffer mixture should be used, shallow layers should be deposited, or drier batches should be used near the top, and the extra water should be drained off through holes in the sides of forms.

The top surface at joints should be trimmed off before proceeding with placing of fresh concrete.

Consolidation must follow immediately upon placing, as once the concrete starts setting, it is not advisable to disturb it. Tamping by means of a wooden rasp, or a light rammer, is helpful. The modern trend is to consolidate by means of an electric vibrator. If vibrators are to be employed, a stiffer consistency can be adopted, resulting in a still stronger and denser concrete. Over vibrating is, however, very harmful, as it causes segregation of the constituents of the concrete.

Curing Concrete: The chemical process of gradual hardening takes place only when water is present. It is, therefore, very important to keep the concrete damp and protect the surface from the sun and drying wind. The growth in the strength of concrete is most rapid during the first few days and progressively becomes slow, so that under favourable conditions of curing, the strength goes on increasing, though slowly, as days, months, and years pass on.

A cover of wet sack, canvas, straw, saw dust, etc. maintained moist, is more satisfactory on the surfaces exposed to direct rays of the sun than occasional sprinkling of water. Horizontal surfaces may be covered by a layer of wet earth or sand, or a pond of water may be formed an inch or so in depth behind clay banks on edges. Columns should be wrapped round with a piece of canvas and a pot full of water with a pinhole at the bottom placed on the top and replenished with water periodically.

Curing must be done at least for 10 days.

Pre cast concrete units can be kept immersed in water after 24 hours.

It has been lately discovered that if curing is done at high temperatures, the rate of hydration of cement can be increased.

In other words, the members cured in warm temperature, develop high strength at an early age. This does not mean that the ultimate strength is increased. Mathematically speaking,

Temperature degrees $\times$ *hours* $=$ *a constant.*

Thus concrete will develop the same strength in 24 days if cured at 20°C (64°F) as it will do in 16 days if cured at 30°C (96°F), or in 12 days if cured at 40°C (128°F). Hence manufacturers of pre-cast articles, such as, pipes, railings, *jali* work, etc. prefer to cure them with steam which supplies both heat and humidity.

Waterproofing Concrete: This has already been described in the chapter on Damp and Its Prevention. (See page 55.)

Devices for Fixing or Anchoring Fitments in Concrete: Bases of columns and machinery are securely founded on concrete blocks by means of special types of bolts, called *rag bolts,* (if small) or lewis bolts (if large), inserted into holes in c.i. or steel base plates. They are manufactured from 16 to 36 mm. (5/8 to 1½ in.) diam. and 12 to 30 cm. (5 to 12 in.) lengths. The holes are subsequently carefully grouted.

The most satisfactory method of attaching fitments to concrete is to build them in while concreting. Another method is to provide wooden plugs of dovetail section, coated with creosote or hot coal tar in the shuttering before concreting.

However, very often a number of fitments, such as railing, pipe brackets, ceiling fans, etc., whose exact positions are not known, have to be fixed long after the concrete has hardened. Again wooden plugs are likely to rot, or be pulled out. To overcome these difficulties a number of patent systems have been developed to provide, with some degree of adjustability, a secure anchorage, from which the fitment can even be detached later at any time and replaced by another. Amongst these the Rawlplug Company's devices are very commonly used in this country. The simplest is the standard Rawlplug. It consists of a cylindrical hollow fibre plug which is inserted into a hole sunk into concrete of a size just to contain it, by a special tool supplied by the company. When a screw is driven into it to fix the fitment, the plug expands and is securely fixed against the sides of the hole. Plugs are made to suit all the sizes of standard screws, and coach screws up to 20 mm. (¾ in.) diam. Tests have shown that a 10 cm. $\times$ 16 mm. (4 in. $\times$ 5/8 in.) diam. coach

screw will resist a pull of 4 tonnes (4 tons). Another type is a Rawlbolt consisting of a split outer metal shell which expands when the nut is tightened. They are available to suit 6 to 20 mm. (1/4 to 3/4 in.) diam. bolts. There are Rawl anchors, Rawl toggle bolts, white bronze Rawlplugs, etc. useful in different situations.

Reinforced Concrete

This subject is so large that it is not possible to do even partial justice to it within the compass of a chapter in this treatise. It is, therefore, intended to make a few general observations on the salient points and to give a few practical hints and tips for the guidance of designing and supervising engineers. For detailed information the student is referred to *A Text book of R.C.C. Design** or any other standard text book on the subject.

Definition: Reinforced concrete is cement concrete in which steel is embedded so that the two help each other in resisting external forces, whether of the nature of flexure, shear, or compression. It is a combination of the two materials in which each is used for the purpose for which it is best fitted.

Advantages of Reinforced Concrete: Among the many advantages of R. C. C., the following are the important ones:

(1) Volume for volume, steel costs about ninety times as much as concrete; and for the same cross section, steel will resist 300 times as much in tension and about 30 times as much in compression as concrete. Therefore, though to support a load in tension, concrete will cost 7.5 times as much as steel, to support a load in compression, it will cost only one third as much as steel. Thus the combination of the two, viz., concrete for compression and steel for tension, makes for an economic design.

(2) R. C. C. is a highly elastic material, and further, it is possible to construct a monolithic structure with it, connecting all the members from the foundation to the top together. An R. C. C. structure, therefore, may become considerably deformed under the influence of an air-raid or earthquake without actually collapsing.

(3) It is a very good fire resisting material.

(4) Masonry is strong in compression, but very weak in

**A Text-book of R. C. C. Design* by R. S. Deshpande.

tension. Reinforced concrete is a sort of masonry which is equally strong both in tension and compression.

Theory of R.C.C. Design: The usual theory underlying the design and construction of R. C. C. structures which is universally accepted and practised is based on the following assumptions.

(i) The bond between steel and concrete is perfect, i.e. no slipping occurs. In other words, an R. C. C. beam behaves as if it were composed of one homogeneous material.

(ii) The strains in a loaded beam are proportional to the stresses producing them.

(iii) A plane transverse section of an unloaded beam remains plane and normal to the radius of curvature after bending.

(iv) Young's modulus of elasticity is the same both for compression and tension.

(v) The working stresses in a beam subjected to loading are within the elastic limits of the materials.

(vi) Steel takes all the tension, and the tensile strength of concrete is neglected.

Out of these assumptions, No. (v), viz., that the working stresses are within the elastic limit, is the most important, because even if they reach the neighbourhood of those at the elastic limit, the first three assumptions on which the design is based fall to the ground.

In order to appreciate this, let us see what happens when an R. C. C. beam is loaded. The phenomenon is this:

For the first time of loading, and a few repetitions thereof, a certain amount of permanent strain results. After this the strain is fairly elastic, i.e., it is recovered as soon as the stress is removed. This elastic strain appears to be fairly uniform with the stress, up to half to three quarters of the ultimate strength beyond which the strain increases faster than the stress.

If the beam is further loaded, cracks are produced on the underside of the beam in the central part; and if the loading is further continued until destruction results, it is observed that the failure occurs finally by the *rupture of the concrete,* crushing occurring at the compressed edge *irrespective of whether the steel is insufficient or in excess* of the requirements determined

by the usual formulæ. *In no case is steel torn out.* What actually happens is this: The steel even though insufficient, being a ductile material, stretches considerably, causing the cracks at the bottom to travel higher and higher, so that the area of concrete available for compression is progressively reduced until it is ultimately too small to bear the load.

On the other hand, when there is an excess of reinforcement, the concrete begins to give way on the compression side and in order to make a larger area available for compression, the neutral axis travels downwards until practically the whole section is made available to resist compression, just as in the case of a flat arch loaded to destruction between unyielding abutments.

The fact that cracks appear much before the elastic limit is reached, indicates that it is really a compound beam in which steel and concrete act largely as separate elements though connected together.

Since concrete does not obey Hooke's law, the fundamental assumption that unit stresses in the fibres at any section are proportional to the distances from the neutral axis, is obviously not true in its case.

The distribution of stress on the compression side, which, according to the assumption, must vary from zero at the neutral axis to the maximum at the top surface, as the ordinates of a triangle, is then more in the shape of a parabola, or an ellipse.

Thus what is generally described as a reinforced concrete beam is in reality an arch, or an elementary frame. If it is a simple beam like a lintel, or slab, its behaviour, when the stresses increase, is like that of a jack arch with a tie rod at the bottom to resist the thrust. A sort of strut is formed inside the beam starting from the ends in an inclined upward direction toward the top, and when web members in the form of vertical stirrups and diagonal shear rods are introduced, it becomes virtually a trussed frame inside the beam or a combination of horizontal and inclined members, something like an N girder, or a lattice girder. Possibly in the central portion, where cracks appear, there may be a frame or truss action, and the ends may act as a homogeneous beam.

Further, though the modulus of elasticity in the case of steel is constant, viz. $2 \cdot 1 \times 10^6$ kg./cm.^{2} (30,000,000) that of concrete, which is assumed to be 14×10^4 kg./cm.^{2} (2,000,000)

is not constant and thus the modular ratio between the two, which is taken as 18:7 (15) for calculations in the usual theory, varies from 11·7 to 14·4 (10 to 18) according to the quality of the concrete, which cannot obviously be guaranteed to be uniform.

Besides, an R. C. C. structure is very rigid in which all the members from the foundation to the top are rigidly connected together, so that if one member is overstressed, it affects the streng h of the others, and altogether new kinds of stresses, such as twisting, might be induced in some of them for which they are not designed.

There are also often uncertainties in data, errors in computations, shrinkage or expansion stresses, unequal settlement of foundations, defective materials, and careless supervision.

From all these facts, coupled with another, that expert supervision during the cons'ruction, which is absolutely essential in the case of an R.C.C. structure, is not always available, the young engineer, who is apt to be very enthusiastic about the "wonderful product of modern scientific research," viz., ferro-concrete, must take a warning to be very cautious in designing R.C.C. structures. The safest course is to allow in no event the working stresses to exceed ¼ *of ultimate strength, or* better still, ½ *of elastic limit*, which is more reliable. The tragedy of the collapse of a building in Bombay in 1942, in which 56 persons were buried alive, should always remain before his eyes.

The maximum working stresses allowed by I. S. Code of Practice (1953) are given in the following table:

TABLE NO. 29

WORKING STRESSES* ALLOWED BY THE INDIAN STANDARD CODE OF PRACTICE IN REINFORCED CONCRETE DESIGN (I.S. 516/1959)

kg. per sq. cm.

(a) Concrete

Approximate Volumetric Proportions	1 : 2 : 4 or 1 : 2½ : 3½	1 : 1½ : 3	1 : 1 : 2
Bending	50	65	80
Direct Compression	40	52	64
Shear Stress	5	6·5	8
Bond Stress	6·5	7·5	9·5

(b) Steel

(I. S. 432/1960)

Compression	m* times the stress in concrete surrounding the steel
Tension	1400 kg. per sq. cm.

*m = Modular ratio of steel to concrete $= \dfrac{2800}{3 \times 50} = 18 \cdot 7$

Reinforcement: Mild steel is most commonly used. There are two grades, viz., soft and hard. The modulus of elasticity for both is the same, viz., $2 \cdot 1 \times 10^6$ kg./cm.^{2} (30,000,000 lb./sq. in.) Soft mild steel, having an elastic limit of 2450 to 2800 (35,000 to 40,000) and ultimate strength of 4900 to 5600 kg./cm.^{2} (70,000 to 80,000 lb./sq. in.), is generally used with a factor of safety of 4. In some patent reinforcing systems high carbon steel ($0 \cdot 5$ per cent of carbon) is used. Drawn wire, which has still greater yield point and ultimate strength, is used in the form of mesh made by welding, in the British Reinforcing Company's (B.R.C.) fabric. Rods also in the form of either corrugated, flat or square, twisted, round, indented or lugged are used. The minimum diameter of the rod is 5 mm. (¼ in.) and the maximum, 40 mm. (1½ in.) The latter is used for heavy columns and beams.

Fig. 615 shows the B. R. C. column and beam system. Some important patent reinforcing systems for partition walls and upper floors are described with illustrations in the respective chapters.

Economic Lay-out of Buildings: The ground plan of a building of a domestic nature is governed partly by the size and shape of the building site and mostly by the requirements of the occupancy, which might vary with the size, purse, idiosyncrasies, etc., of individuals and so no general rules can be laid down. However, in the case of industrial buildings of the factory or warehouse type, a few general principles can be given, the application of which is sure to result in economic design.

Unless the location of columns is controlled by the architectural requirements, columns may be spaced 6 to 8 m. (20 ft. to 25 ft.) apart between centres, making approximately square panels between them. Whatever width is required for the build-

ing, it should be equally divided into at least three bays, in order that the beams may be made and designed as continuous, which are economical. The exterior, as well as interior, columns should be arranged in rows, either parallel or at right angles to each other, and in such a way that their centres will lie on the centre lines of the rows. This simplifies the calculations as well

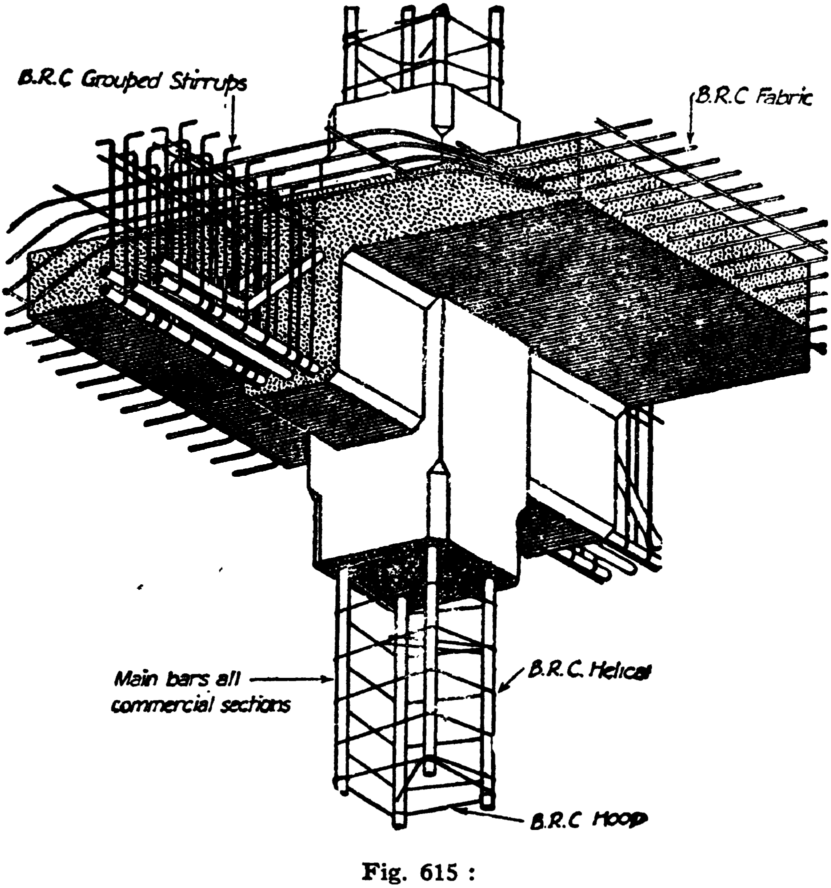


Fig. 615 :
B. R. C. column and beam system.

as the construction. Isolated interior columns may be of square, oblong, or round section but those attached to partition walls should be of rectangular section. The exterior columns are usually of rectangular section, and their width on the face is kept constant for the entire height. The thickness may be lessened to reduce the

necessary cross sectional area, commensurate with the reduced loads they are to support.

Design Procedure: The first step is to prepare a preliminary framing plan showing the columns, beams, bearing walls, if any, partitions, etc., and openings requiring framing. Location of staircases, sanitary services, and drain pipes should be considered. Also, adequate means of lighting and ventilation should not be lost sight of. Out of a number of different plans, the one which satisfies the requirements best and at the same time is the most economical, should be finally adopted.

After this, detailed design of beams and columns should start from the top downwards. Regarding floor slabs—a design of preferably the ground floor if there is a basement, or the first floor if there is no basement—should be made, as this is likely to repeat itself, for the upper floors. The design of slabs will come first, followed by that of beams. As a first approximation, the thickness of R. C. C. slabs and beams should be calculated at 40 and 80 mm./m. (½ in. and one in./foot) of span, respectively. The live load and load per sq. m. (ft.) of area on columns should be calculated from the topmost column supporting the roof downwards, every time the weight of the columns themselves and that of super-imposed walls, etc. should be added. The footings of columns follow next for the design. Parapet walls, stairs, etc. are the last items to be designed in detail, but their approximate sizes must be assumed beforehand at early stages for the calculation of the total dead load.

Random Practical Hints and Tips: *Footing Beams of Wall Foundation:* The minimum depth of such beams should be 22 cm. (9 in.) They are usually designed as continuous beams, and the reinforcement is equally divided and placed at bottom and top. The minimum width of beams should be 15 cm. (6 in.) more than the width of the wall at footing.

Independent Bases of Columns: These may be either rectangular blocks of constant section or with tapering top. The latter save a little concrete, but the formwork is costly.

Piles are not economical unless the depth is at least 8 m. (25 feet.)

If the soil has a very low bearing capacity, raft foundation may be adopted. Rafts are designed like ordinary floor slabs, but inverted with a uniform pressure distributed from below

equal to the bearing power of the soil and the columns as the supports.

Walls and Partitions: In R.C.C. construction, the external walls hardly carry any load except their own. Hence, a small thickness is sufficient, but a minimum of 15 cm. (6 in.) is required for protection from heat.

Basement walls which have no footings may be designed as deep beams to carry their own weight and bear lateral water pressure, if the ground is water-logged. As the depth is considerable, the steel required would be very small, but the shear would be great. In that case, they may be designed as beams spanning the distance between the columns, in strips of one foot depth and suitably reinforced. If the depth is less than the distance between columns, they may be designed as continuous beams.

Floors: R. C. C. floors may be classified into three main divisions:

(a) Beam and slab floors, of which T-beam floor is a variety.

(b) Hollow floors, or floors in which the gaps between the R. C. C. ribs are filled with either pre-cast hollow tiles or steel sheet cores.

(c) Flat or beamless slabs.

The problem of R.C.C. floor construction is discussed briefly in the chapter on Construction of Upper Floors.

Reinforced Brickwork: This is now a recognised standard method of construction, particularly for slabs supported on walls and lintels. It can be as accurately designed as reinforced concrete on the same principles as the latter. The only difference is that the reinforcing bars have to be placed at particular distance apart to suit the size of bricks. The bricks used must be specially selected, hard, and well burnt, and the joints must be filled with concrete. The thickness of slab is controlled by the size of the bricks which may be laid either flat, or on edges, or, if still greater thickness is required, they may be used in two layers, one upon another. The advantage of reinforced brick construction is that it requires little or no shuttering, or subsidiary mixing plant and gives a fair face which requires no further treatment. Further as bricks are used to substitute bulk of concrete, it is much cheaper.

As regards stresses, the working stress in compression may be from 20 to 35 kg./cm.^{2}* (350 to 500 lb./in.^{2}) depending on the quality of bricks, shear stress of 2 kg./cm.^{2} (30 lbs./in.^{2}) and $m = 40$. The tensile stress in steel may be as usual viz., 1400 kg./cm.^{2} (18,000 lbs./in.^{2})

For $m = 40$, the constants are : $n = 0 \cdot 36$, $j = 0 \cdot 88$, $Q = 3 \cdot 2$ and weight of R. B. work $= 2100$ kg./m.^{3}

This construction is applicable to slabs, lintels, columns, beams, and walls, but columns and beams are not common as the others.

Bibliography:—*Reinforced Brick-work* by Brebner (in two volumes).
Reinforced Brick-work—A paper published in the in the Journal of A. R. I. B. A. 1937.

*20 kg./cm.^{2} for ordinary bricks to 35 kg./cm.^{2} for selected bricks.

Questions for Revision

(1) What is the difference between a rapid-hardening and normal-setting cement as regards their composition, grinding and action? Under what circumstances is rapid-hardening cement profitably used?
(2) What is the function of water in concrete?
(3) Describe the slump test of concrete in detail with a sketch of the apparatus.
(4) What is the best method of determining the correct proportions of coarse and fine aggregate?
(5) How does bulking of sand affect a concrete mixture? What is the remedy?
(6) What should be done to a certain mixture which works harsh, so as to make it workable without impairing the strength?
(7) How will you proceed with the designing of an R. C. C. frame of a large industrial building provided the site is unrestricted?

STRUCTURAL STEELWORK : 17

THE employment of steel framework to carry the loads of a building is so common at present that architects and civil engineers must possess a working knowledge of this form of construction.

Detailed design of structural steel work is outside the scope of this treatise, and the student is referred to any standard book dealing with that subject. Only the general principles and the practical aspect of design and construction are discussed here. These are given below:

(1) Although rolled steel sections have been standardised, and tables of their properties, such as area, weight, moment of inertia, modulus of section, radius of gyration, etc., worked out with mathematical accuracy, are at one's command, much depends upon the skill and experience of the designer to make the best and most economical design. For instance, out of the two R. S. joists,

$$250 \text{ mm} \times 125 \text{ mm} \times 37 \cdot 3 \text{ kg./m}$$
$$300 \text{ mm} \times 140 \text{ mm} \times 44 \cdot 2 \text{ kg./m}$$

the second, though a trifle heavier, is much stronger and stiffer than the first. As another instance, two 300×140 mm. rolled steel joists, each weighing $44 \cdot 2$ kg. per m. run, supply about 40% bigger modulus of section and thus possess the much higher strength.

(2) The basic principle of design, apart from the general lay-out, which is perhaps more important, should be that each member, under bending stresses, should be as deep as possible in the direction of the maximum bending moment.

(3) It is not advisable to reduce weight for the sake of economy without regard to the cost of labour, which is perhaps equally, or, often, more important. For instance, weight can be

saved by substituting lattice for plate girders, or compounds for single rolled sections; but in these cases, the cost of labour, per ton is bound to be higher than that of the material saved.

(4) When in doubt, the safest, though more laborious course is to work out the final costs of alternative designs.

(5) Joints should be designed with due regard to the difficulties of transport, erection and subsequent maintenance (painting).

(6) Cleats should be so arranged that they may be riveted, as far as possible, in the shop, making the number of bolts and rivets to be fixed on the site as few as possible.

(7) The various members should be self-supporting without the use of lifting tackle while connections are being made.

(8) Although steel is adapted to any complicated design, its cost rapidly increases with complexity, while the cost of brickwork does not rise so appreciably.

(9) If a steel frame work is to be made, it should be done right from the foundations to the roof, tying and bracing the different parts together, and not piling up steelwork from the first floor without regard to lateral bracing. The former is advantageous from every point of view—stability, economy, and protection.

(10) Steel embedded in brick or in concrete (unless it is an R. C. C. design) should not be designed to carry loads together in the same pier or wall. Either the brickwork or the steel member must be strong enough to carry the entire load.

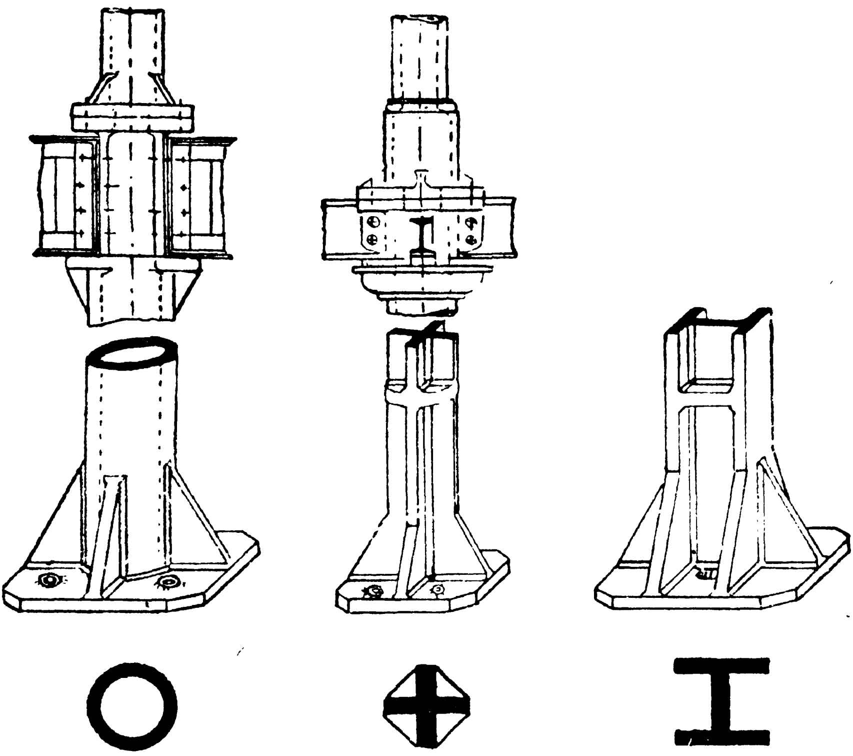
(11) Care must be taken to see, when erecting a building, that the calculated loads, and no more, are brought to bear on the steel work. This is not so important if brickwork is used instead of steel.

(12) In the interests of economy, good appearance, and simplicity of erection, and also of calculation, it is desirable to place columns in such a manner as will make the spacing uniform, giving as many rectangular panels as possible. Curved or circular work should be avoided as far as possible.

(13) Skew framing and eccentric loading should be avoided, and girders should be directly connected into the columns.

(14) Columns supporting upper floor loads and roof should, wherever possible, be continuous from the foundations

and if it is necessary to splice, it should be done at 45 cm. (1′ 6″) above the floor level. Where practicable, they should be so placed as to support directly the girders upon which heavy walls are resting.



Figs. 616—623 :
Common forms of cast iron bases and capitals.

(15) It is absolutely necessary to have complete figured drawings, and all the work should be done entirely to drawings and not to measurements taken on the site from time to time as the work progresses. The drawings must be properly checked in every detail, the material carefully inspected, and steel erected, accurately to drawings and specifications.

Materials most commonly used in structural work are cast iron, wrought iron, and mild steel, the most important of these being mild steel.

Cast iron is very strong in compression, and therefore, it is very much suited to columns and struts. C. I. columns are relatively cheaper than those of steel; they can be obtained readily and fitted with suitable brackets and flanges so that the erection cost is reduced. Further, C. I. columns resist fire better, and corrode or rust less than steel columns. But though C. I. has very high crushing strength 5600 kg./cm.^{2} (80,000 lbs./in.^{2} or even more) its dependable strength in tension or shear is very low and uncertain. Even thorough inspection of castings may fail to reveal internal defects—honeycomb, air-bubbles, cinders, foreign matter, etc. which may seriously affect the strength. Flaws in the metal and initial stresses caused by shrinkage or unequal cooling may cause the material to fail under small loads suddenly applied. Further, it is very brittle and cannot be punched or riveted. Consequently, all the connections must be bolted. It is extensively used for the bases and caps of columns but, as a material even for columns for which it is most suited, it is being substituted by mild steel in modern practice. It was, until a few years ago, used in heavy sections even for beams, but it is now scarcely used for that purpose.

Other uses of C. I. in building construction are for brackets, king-post heads, staircases—treads and risers and also balusters and newel posts,—soil and drain-pipes, etc.

Figs. 616 to 618 show a circular hollow C. I. column in which all the metal is utilized to the best advantage. For fire protection, it is encased in brickwork. Figs 619 to 621 show a square ribbed C. I. column which comes next in popular use. It is encased in terra cotta hollow blocks or concrete for fire protection. The channel sections of C. I. column shown in Figs. 622 and 623 are occasionally used for columns.

Wrought Iron: A soft, tough iron, showing silky, fibrous texture, is good. In building construction it is used in the form of rivets, bolts, rods, bars, small diameter water-pipes, flat and corrugated sheets, etc. It is more easily welded than steel, because the work can be accomplished through a wide range of temperatures.

Corrugated iron sheets are used for roof covering. They are usually galvanised and in lengths from 1·5 to 3 m. (5 to 10 ft.) and in widths of either 66 or 81 cm. (26″ or 32″) (thickness 16 to 26 wire gauge). Out of these widths, 5 cm. (2″) go in the lap,

and the useful widths available are 60 cm. and 75 cm. (2 ft. and 2½ ft.) respectively.

TABLE NO. 30*

APPROXIMATE WEIGHT IN LBS. PER SHEET

Wire Gauge	5 ft. Long lb.	6 ft. Long lb.	7 ft. Long lb.	8 ft. Long lb.	9 ft. Long lb.	10 ft. Long lb.
16	32	38¾	45	51	57½	64
18	26	31	36	41½	46¾	52
20	19¾	23½	27¾	31½	35½	39¼
22	16¼	19¼	22¾	25¾	29	32½
24	13¼	16	18¾	21½	24	27
26	10	12	14¼	16	18¾	20¼

TABLE NO. 31*

APPROXIMATE NUMBER OF SHEETS PER TON

Wire Gauge	5 ft. Long	6 ft. Long	7 ft. Long	8 ft. Long	9 ft. Long	10 ft. Long
16	70	58	50	44	39	35
18	86	72	62	54	48	43
20	114	95	81	71	63	57
22	139	116	99	87	77	69
24	168	140	120	105	93	84
26	223	186	160	140	120	110

TABLE NO. 32*

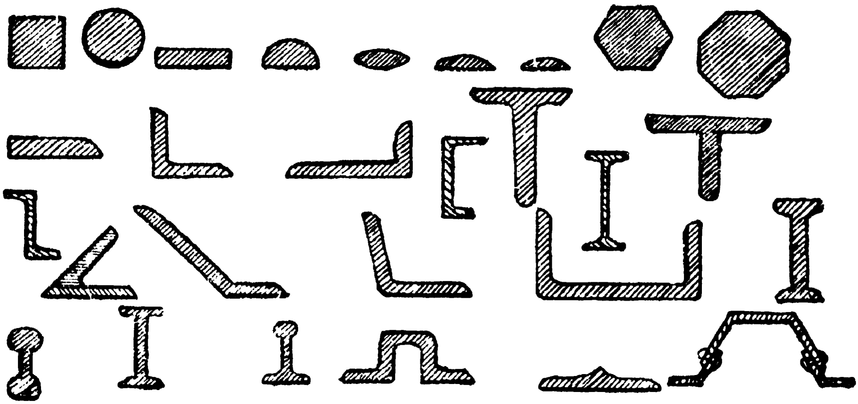
AREA COVERED BY ONE TON OF CORRUGATED SHEETS AFTER ALLOWING FOR THE LAPS

Gauge	16	18	20	22	24	26
Square ft.	600	800	1020	1280	1530	2100

* The metric standards for G.C.I. sheets have not been laid down by I.S.I. as yet.

Steel : Structural steel is manufactured either by the Bessemer or the Open Hearth process. That manufactured by the latter process is preferred, as it is more uniform and dependable in qua-

lity. Mild steel combines all the best qualities of cast iron and wrought iron, and is harder, tougher, and sounder than the latter.



Figs. 624—651 :
Different sections of mild steel manufactured for structural use.

The different sections of mild steel used in structures are shown in Figs. 624 to 651.

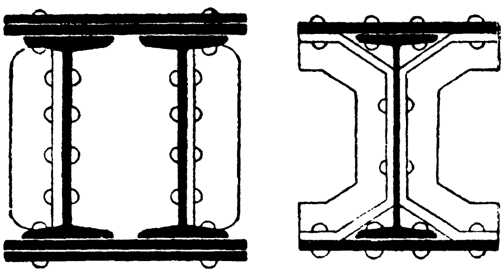
All these rolled steel sections have now been standardised and tables of their properties are available. These considerably simplify the work of designing structural members.

Beams* : Beams used in buildings may be either simple rolled steel sections in one piece, or compounded or built up of one or more rolled beams with the addition of flats riveted on the top and bottom of flanges, thus increasing the flange area for obtaining extra strength and also to secure a greater width of top surface upon which to build. When still greater width is required, one or more parallel girders are joined together to make one complete structure. This is best done by means of simple cast iron packings or separators bolted through the girders. When the load is so heavy that even the girder giving the largest sectional area is found inadequate, a plate girder as shown in Figs. 652, 653 is built up by riveting or welding together the different parts.

* "Beam" and "Girder" are general terms, though the term "girder" is applied to larger sections. The term "joist" is applied to smaller sections used in floors at short distances apart. "Bressumer" is a lintel or a beam intended to carry an external wall, and is itself supported on piers or posts. It is used principally on shop-fronts.

When designing beams, the following points should be noted:

(a) Though continuous girders and girders with fixed ends are theoretically subjected to smaller bending moments than non-continuous ones with free ends, this is only on the assumption that (1) the ends are absolutely rigid, and (2) the various supports of the continuous girders are exactly in a line and their settlement is exactly equal. This is very difficult to achieve in practice, and if this is not accomplished, they are subjected to greater bending moments than if they were on independent spans with free ends. It is, therefore, safer to adopt the non-continuous form. This incidentally, saves labour in calculation.



Figs. 652, 653 :
Typical sections of plate girders.

(b) When joists are heavily loaded, special calculations should be made to ensure that the deflection is within safe limits. In fact, it is a safer policy to consider deflection to determine the size of joists. The usual deflection allowed is 1/360 of the span, but when the joists have to support a plastered ceiling, this should be reduced to 1/480.

(c) Single girders and joists, particularly those which have narrow flanges, unless laterally supported or encased in concrete are likely to be weak in resisting flexure in a horizontal plane, or lateral bending. A girder may fail by lateral bending of the top flange rather than of the vertical web.

(d) The bearing plates and the templates of stone or concrete below them should be sufficiently large to distribute the load on the wall without exceeding the safe bearing stress of the material of the wall.

(e) Stone templates or corbels carrying heavy girders should be chamfered at the front edge to prevent chipping or spauling, which is likely to happen under a concentrated load near the edge.

Columns* : The design of a column is dependent on several factors, such as slenderness ratio i.e., the ratio of its effective length to the least radius of gyration, eccentricity of loading, and the condition of the fixity of ends. Particularly in respect of the last factor, the designer has to exercise his judgment.

Broad-flanged sections are specially rolled to suit the requirements of columns and their use is most economical. However, whenever circumstances demand a still heavier section, it can be built up by compounding different sections together by rivets.

The compound sections suitable for columns are shown in Figs. 654 to 658.

The choice of the section is very often governed by considerations of fixing and the dimensions of the neighbouring parts. However, simple good connections and ease of fabrication in the shop are factors of no smaller importance in the selection. Steel columns tend to fail by bending in the direction of their least dimension, and so sections, which have approximately equal moments of inertia about their two principal axes, are most suitable. Channel columns give good results with regard both to strength and cost. Two I-beams are not only uneconomical, but they do not permit good connections on the flange side. For light loads, four angles may be used with advantage as shown in Fig. 657. For several reasons angles are cheaper per ton, the combination is stronger laterally than that of I beams, only two rows of rivets are required and lastly, the modulus of the section can be obtained by using plates and angles of the desired thickness.

The same shape of column should be used for the whole height as splicing is then easier, and a better support to the columns above is obtained.

A few typical bases and caps of steel columns and their connections are shown in Figs. 659 to 666.

Cover to Steel Work: The cover serves not only as protection against fire but also against corrosion. Hence it is unwise to

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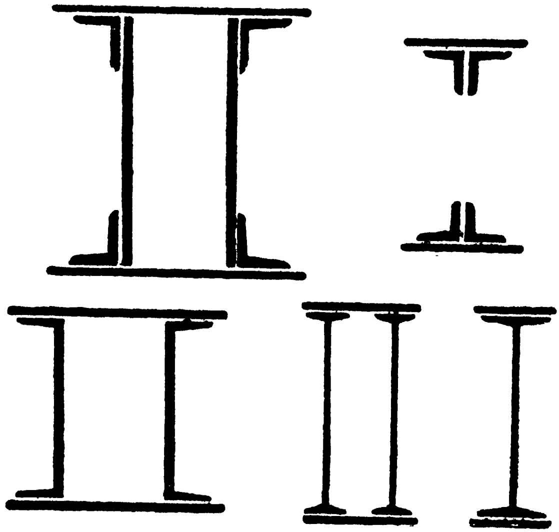
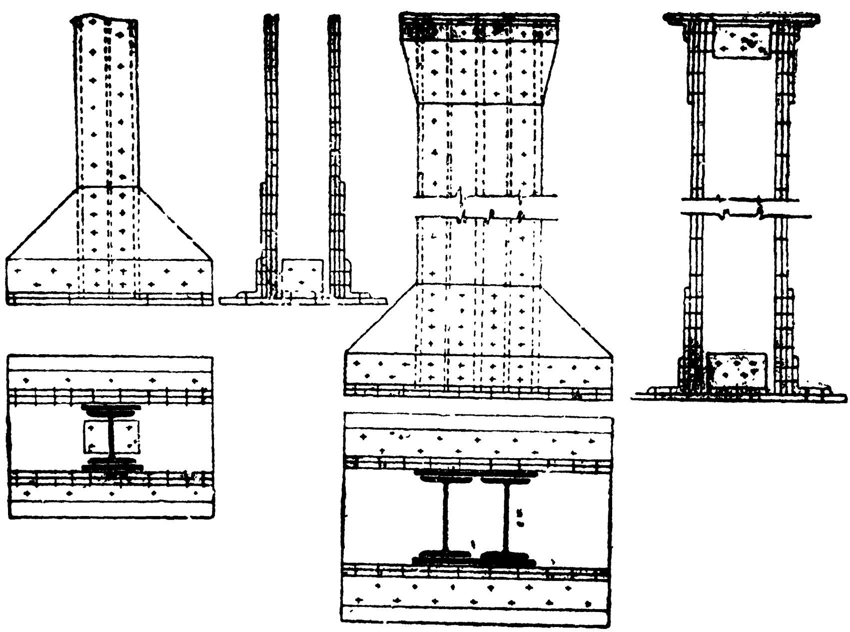
* NOTE—The term "column" is a general one applied to small as well as large vertical members supporting a light or heavy load. "Stanchion" is the term applied to columns carrying a heavy load. The term "pillar" is sometimes applied to a cast iron, round column. A "strut" is an inclined member under compression. A "post" is usually of timber, either square or round.



Figs. 654—658 : Horizontal sections of columns of different types.

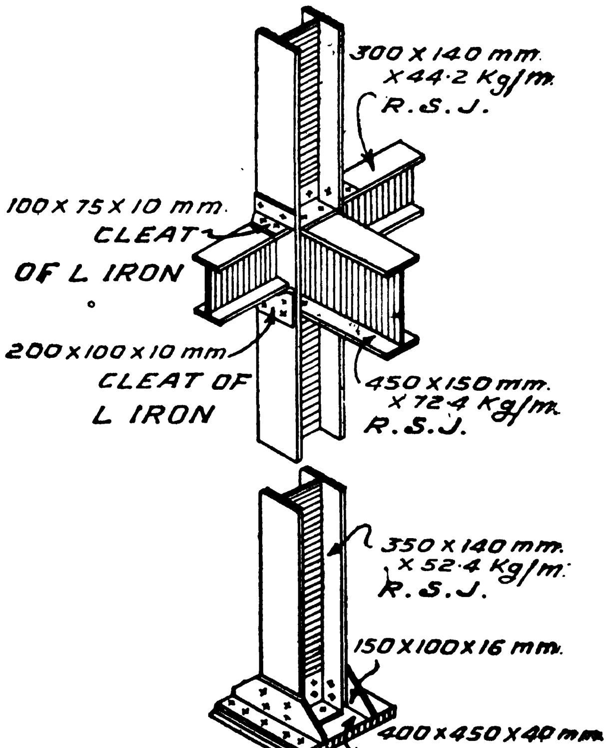


Figs. 659—666 : Bases and Caps of M. S. columns.

reduce it beyond certain limits or to use porous materials. Concrete casing should be reinforced with light wire mesh. L. C. C. By-laws require covers as follow:

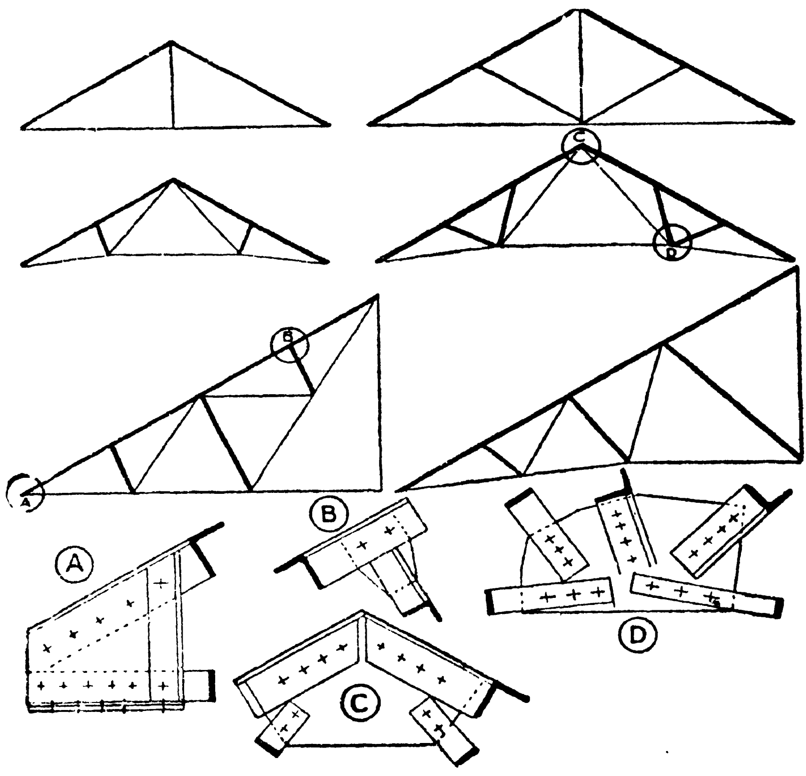
Columns in external walls	10 cm. (4 in.) on all sides.
Other Columns	5 cm. (2 in.) on all sides.
Beams in external walls	10 cm. (4 in.) except to underside and edges of ges which may be 5 cm. (2 in)
Other beams	5 cm. (2 in.) except to upper surface of fiange which may be 2·5 to 3 (2 in.)

Steel Roof Trusses: Mild steel trusses have now practically superseded timber trusses even for spans as short as 8 m. (25 or 30 ft.) This is on account of lightness, immunity from attack of white ants and dry rot, greater fire resistance, and the ease with which the various members can be machined and shaped in a workshop, and subsequently packed and transported to site for assembly.



Figs. 667, 668:
Base of a steel column and beam connections.

As far as possible all members of a truss should be subjected to either direct compression or tension but sometimes the transverse stresses are unavoidable, such as in a tie-beam with the ceiling attached to its underside, or a principal rafter carrying a purlin, etc.



Figs. 669—678 :

Steel roof trusses and their joints. In Figs. 669—678 the compressive members of trusses are shown in thick lines and tension members in thin lines.

The struts should be as short as possible, and the principal rafters subjected to transverse stresses should not be longer than 3 m. (10 ft.) maximum. The tension members should be braced together.

The sections commonly used for compression are either angles or tees. Flats and rounds may do for tension members, but when a certain stiffness is required, angles and tees are used. If a

flat is used, it should be laid on edge to give it a stiffness against sagging.

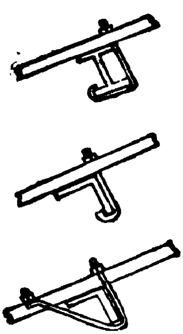
If a ceiling is to be attached to the underside of a tie-beam the form of the truss adopted is shown in Figs. 669, 670 and 673. Otherwise, the form known as an open truss, with a camber given to the tie-beam as shown in Figs. 671 and 672 is used. The latter makes the length of the struts shorter and affords a greater head room below the truss.

The ends of the members to be jointed are grouped together, and the joint is made by using a common gusset plate of a minimum thickness of 8 mm. (3/8 in.) The diameter and number of rivets, and also the thickness of the gusset plate, are designed to resist the maximum shear, and the design is adopted uniformly for the whole truss. The number of rivets at the end of each member is uniform.

The distance apart of the trusses should not exceed 3 m. (10 ft.)

For small spans the ends of trusses should rest on a lead sheet, and the holes drilled for the bolts for fixing them should be oblong slots to allow some lateral movement to the truss for expansion due to heat.

In the case of long span trusses, one end should be fixed, and the other should rest on a chair mounted on steel rollers for a free lateral movement.


Figs. 679—681.

Enlarged details of the joints at A, B in Fig. 673 and at C, D in Fig. 672 are shown in Figs. 675 to 678.

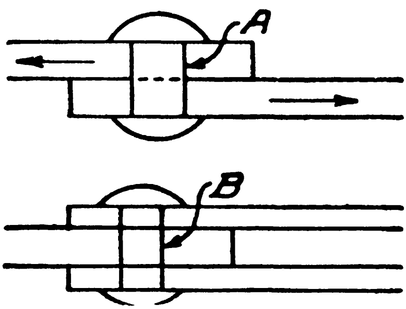
Wind ties in the form of either flats or rounds should have one end secured to the foot of the principal rafter of one truss, and they should pass diagonally across three or four trusses to which they should be rigidly secured until they reach the ridge.

If corrugated iron sheets are used as the roof covering on the top of steel trusses, steel wire bolts of one of the patterns shown in Figs. 679 to 681 should be used to secure them to the steel purlins.

Joints of Structural Members: These are made in either of the two ways:—(1) Riveting, or (2) Welding.

Riveted Joints: The process of riveting consists of first punching or preferably drilling holes in the plates to be riveted, 1·5 mm. (1/16″) larger than the diameter of the rivet as the latter considerably expands when heated to red heat. In workshops the rivets are "closed" in the work by a hydraulic press consisting of two cup shaped jaws, one fixed and the other free to move, under a pressure of 15 to 20 tonnes (tons.) In field this is done by delivering a large number of blows either by hand or by a pneumatic hammer. The cup shape of the tool produces "snap" heads.

If the riveted plates are tested for tension, failure will occur by shearing of the rivets. The latest L. C. C. Regulations permit a working stress of 950 kg./cm.² (6 tons p. s. i.) in rivets in single shear as at A and double this or 1900 kg./cm.² (12 tons p. s. i.) in double shear as at B. (Figs. 682 and 683). Thus the shear strength of a 18 mm. (¾ in.) rivet will be 2·54 × 950 kg. = 2·41 tonnes (0·44 × 6 = 2·64 tons) in single shear and 4·82 (5·28) in double shear. Actually the friction between the plates increases the resistance considerably, but as this factor is uncertain, depending upon several circumstances, it is not taken into account.



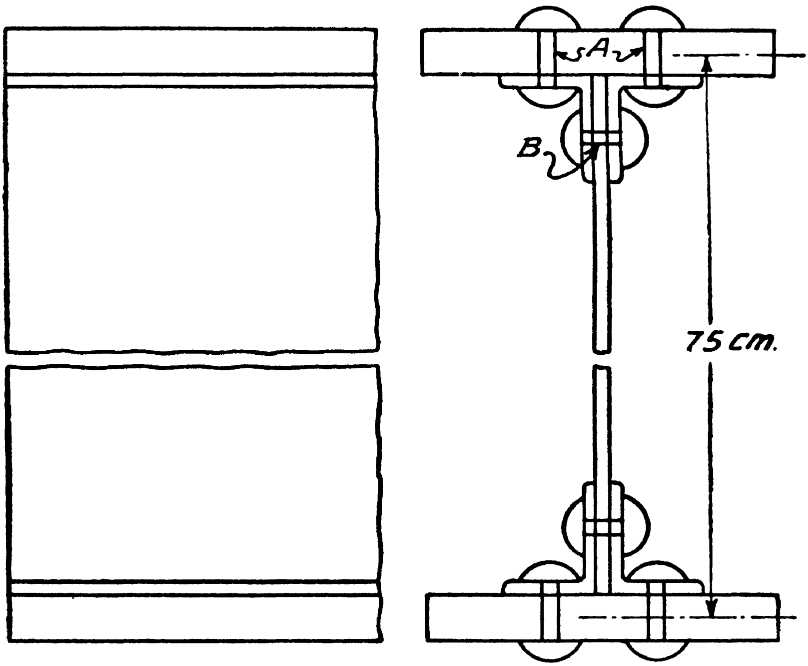
Figs. 682, 683: Snap-headed rivets in single and double shear.

If a rivet is very long as compared with its diameter, the shrinkage stress induced in it during cooling is so great that it may even break it. It is therefore customary to use rivets of maximum lengths equal to five times their diameter, beyond which bolts are used. However, a bolt of the same diameter is not as strong as a rivet as the latter expands and fills the hole completely, and again the cutting of threads round a bolt reduces its diameter and section.

Design of Rivets : This will be clear from the following example.

Example: A built-up beam as shown in Figs. 684 and 685 spans a distance of 6 m. and carries a central load of 50 tonnes. Design the spacing of 18 mm. rivets, neglecting the weight of the beam for simplicity.

Solution: The total vertical shear and therefore also the horizontal shear, say, at 1 m. from the support must be 25 tonnes. As the depth of the beam is 75 cm.,



Figs. 684, 685.

$$\text{Shear per m. run} = \frac{25}{\cdot 75} = 33\cdot 33 \text{ tonnes}$$

The strength of each 18 mm. rivet $= 2\cdot 54 \times 0.95 = 2\cdot 41$ tonnes. There are two rows of rivets at A, one on either side of the web, i.e. two rivets. Their combined strength will be $4\cdot 82$ tonnes.

$$\text{Spacing} = \frac{100 \times 4\cdot 82}{33\cdot 3} = 14\cdot 46 \text{ cm.}$$

We shall adopt a spacing of 14 cm. of the rivets in the flange. As regards the rivets in the web, though there is one rivet only as at B, it is in double shear. Therefore, its strength

will be the same viz. 4·82 tonnes. Hence the same spacing as that in the flange will do. Its strength per m. run will be $= \frac{4 \cdot 82 \times 100}{14} = 34 \cdot 43$ tonnes against 33·3 tonnes required.

Welded Joints: During the past few years, particularly since World War II broke out, the art of welding has developed to such an extent that it may, perhaps, altogether oust the time-honoured riveting from the field of Structural Engineering.

Advantages of Welding: (a) Use of the entire cross section of the tension members, since there are no rivet holes to be subtracted.

(b) Less material required for end connections, since webs of beams and girders can be welded direct to other girders or to columns without the use of connecting angles.

(c) Use of outstanding plates, instead of angles, for stiffness.

(d) Elimination of the noise of riveting, which is an important advantage in cities.

(e) Rapidity of erection. Riveting is a laborious process, particularly in corners and other places not easily accessible.

(f) Economy in jointing when the work is on a large scale.

Welded joints are made by fusion, using either oxy-acetylene gas or electric arc. The former is cheaper, but the gas is not as commonly at hand as electricity. In electric welding, the fusing of the edges of the parts is effected by a sustained electric spark or arc formed between a metallic wire clamped to a negative electrode held in the hand by the operator and the work itself which forms the positive electrode. In the process, the wire is melted and fuses with the adjoining edges of the parts to be welded and forms a joint.

Tests made have shown that if the welding is properly done, it is possible to develop the full strength of the members joined.

L. C. C. Regulations in respect of welding are as follow:— The electrodes used must comply with B.S. No. 639. The working stresses allowed are given on page 325.

Thus if 3 mm. (1/8″) plates are to be butt welded either in tension or compression, from the Table No. 33 a stress of 400 kg./cm. (one ton per linear in.) of weld can be allowed; if they are 6 mm. (1/4″) plates, 800 kg./cm. (2 tons/in.) run is allowed.

Figs. 686 to 693 and Table No. 34 illustrate the general conditions governing detailed preparation of surfaces and weld sizes.

The surfaces of materials for a distance of 12 mm. (½″) from the joint should be cleaned of dirt and grease, paint, heavy rust, etc. While welding, care must be taken that the parent metals are not damaged. The pieces should be held securely during welding and all distortion should be eliminated. The slag must be chipped from finished welds, which, with the adjacent portions of parent metal may be coated with linseed oil.

TABLE NO. 33

Classification of Stress in Welded Connection	Maxi. permissible stress in kg./cm.^{2}
Tension and compression in butt welds	1250
Shearing in butt welds in webs of plate girders and joists	950
Shearing in butt welds other than webs of girders and joists	800
Stress in fillet welds	950
Stress in side fillet welds, diagonal fillet welds and tee fillet welds.	800

Design of Welded Joints: We have seen above that there are two types of welded joints: butt welded and fillet welded. In butt welded joints we fill metal between the two pieces of work, of the full section as the parent metal, i.e. the two pieces become one. Therefore provided the electrode used is of standard quality and other precautions are taken, the joint is supposed to be as strong as a solid piece of the parent metal. There are, therefore, no calculations.

The strength of a fillet joint, however, depends upon the section and length of the triangular portion or the "throat" of the fillet. Assuming the filling is done at 45° angle, and if x is the length of either the horizontal or vertical side of the triangle, the area of the throat is $x \sin 45° = 0{\cdot}7x$. This multiplied by the length of the fillet and the working stress gives the strength of the joint. From Table No. 33 it will be seen that a stress of 950 kg./cm.^{2} is allowed for a fillet joint either in tension or compression, and 800 kg./cm.^{2} in shear (diagonal or T fillet). From this a joint can be designed. The following example will make this clear.

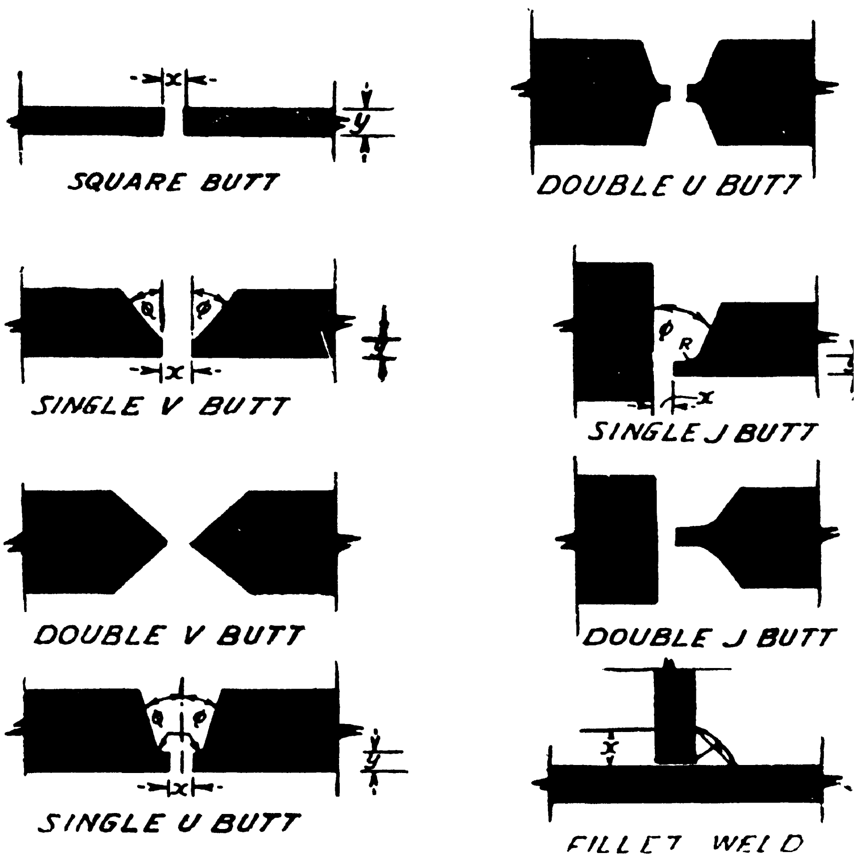
TABLE NO. 34

GENERAL CONDITIONS GOVERNING PREPARATION OF SURFACES AND WELD SIZES AS RECOMMENDED BY L. C. C. REGULATIONS

Kind of Weld	Fig. No.	Remarks
1. Square Butt	686	*x* to be not less than 1.5 mm. and *y* not more than 4.7 mm.
2. Single V Butt	687	*x* to be not less than 1.5 mm. for thickness less than 9 mm. *x* to be not less than 3 mm. for thickness 9 mm. or more. *y* to be not more than 1.5 mm. for thickness of 12 mm. or less. *y* to be not more than 3 mm. for thickness of more than 12 mm. ϕ angle to be not more than 50°
3. Double V Butt	688	Conditions as for Single V Butt
4. Single U Butt	689	*x* to be not less than 3 mm. *y* to be not more than 3 mm. for thickness of 12 mm. or less. *y* to be not more than 3 mm. for thickness of more than 12 mm. ϕ to be not less than 10°. R radius to be not less than 3 mm.
5. Double U Butt	690	Conditions as for Single U Butt
6. Single J Butt	691	*x* to be not less than 3 mm. *y* to be not more than 1.5 mm. for thickness of 12 mm. or less *y* to be not more than 3 mm. for thickness of more than 12 mm. ϕ angle not less than 20°, nor more than 30° R, radius to be not less than 3 mm.
7. Double J Butt	692	Conditions as for Single J Butt.
8. Fillet Weld	693	*x* = Throat thickness as shown in the figure.

Example: A tie rod 100 mm. $\times$ 9 mm. subjected to a tension of 12 tonnes is to be joined to a member of a roof truss. Calculate the length of the fillet.

Solution: From Figs. 694 and 695, it will be seen that the fillet at the end of the plate which is at right angles to the direction of the load is in tension, and that at the side which is parallel to the direction of the load is in shear. Hence according to the

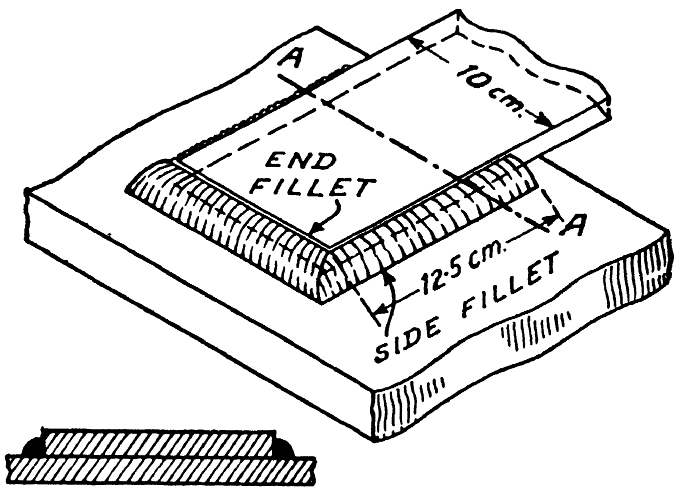


Figs. 686—693

L. C. C. Regulations, a stress of 950 kg./cm.^{2} is to be applied to the end or transverse fillet and that of 800 kg./cm.^{2} to the side or longitudinal fillet. Assuming the length of the side of the throat 6 mm., the strength of the end fillet will be = area of throat $\times$ length of fillet $\times$ working stress = $0 \cdot 6 \times 0 \cdot 7 \times 1 \cdot 0$ cm. $\times$ $0 \cdot 095 = 3 \cdot 97$ tonnes.

We want 12 tonnes, so we must provide a strength of $12 - 3 \cdot 97 = 8 \cdot 03$ tonnes in side fillets. If $x =$ length of one side fillet i.e. $2x =$ that of the two sides,

$$8 \cdot 03 = 2x \times 0 \cdot 6 \times 0 \cdot 7 \times 0 \cdot 7875 \text{ tonnes}$$



Figs. 694, 695:
Plan, and Section on AA.

or, $x = 12 \cdot 12$ cm. We shall provide $12 \cdot 5$ cm. since a length equal to twice the thickness of weld is neglected as it is possible that the ends may not be of full cross section and the metal also may be of poor quality. Hence the side lengths of the fillet will be 12.5 cm.

In the interest of strength and safety certain rules are observed in the case of fillet welds. The important ones of these are:

A combination of end and side fillet is stronger than either an entirely end or entirely side fillet.

If fillet weld is made only at sides, it should be turned round both the corners for a length of at least 25 mm. (1″).

If fillet weld is only on sides, the length of the fillet on each side should not be less than the width at the end, or the perpendicular distance between the side fillets.

Questions for Revision

(1) What are the common uses of c i. in building construction, and why? Name any three uses of c. i. in building wo.k.

(2) Why has m. s. superseded c. i. and w. i.? What are the following made of: vertical drain and soil pipes; corrugated galvanised sheets; water supply pipes for domestic use; brackets; railing.

(3) What are the advantages of welding over riveted joints? Sketch welded joints of 32 mm. round soiid bars used for R. C. C. work in (i) columns, (ii) beams.

PAINTING AND DECORATING : 18

THE object of applying a paint is to protect the material from atmospheric influences. A paint prevents decay in wood and corrosion in metal. It also provides colouring, and hides the roughness or unattractive appearance of the surface, and by giving a gloss and smoothness to the surface brings out a decorative effect.

Materials: A paint essentially consists of two things: (1) a base of solid matter which supplies *body* i.e., opacity to obscure the surface and (2) a liquid vehicle which carries the solid matter and allows it to be evenly spread on the surface. The vehicle also forms a binder for the solid matter and causes it to adhere to the surface.

There are other accessories required, viz., pigments, colours or stains, driers, and thinning agents.

The Base: The base may consist of white lead, red lead, zinc white, iron oxide, or graphite. White lead, by far, is the most common.

(A) Pure white lead is labelled *genuine,* and when adulterated it is labelled *reduced.*

No. 1 *reduced* contains 70 to 80 per cent of white lead.
No. 2 *reduced* contains 50 to 60 per cent of white lead.
No. 3 *reduced* contains 40 to 50 per cent of white lead.
No. 4 *reduced* contains 20 to 30 per cent of white lead.

The usual adulterant is ground barytes (barium sulphate). Even genuine white lead may be poor in quality, which depends upon the colour, condition of grinding, freedom from grit and skins, etc. White lead is cheap and possesses the advantages that it is easily applied and has a good *body* to obscure surface; but it is susceptible to the fumes of sulphuretted hydrogen, and gets yellow or brown by its action. The atmosphere in industrial towns has sulphuretted hydrogen present in it. It is, therefore,

used for undercoats, and the finishing coat is of white zinc or some other material which does not get darkened by the influence of this gas.

Lead paints have the further great disadvantage that if absorbed into human system by respiration in the form of dust, while scraping old painted dry surfaces, or the fine spray of a spraying machine, they work as a poison. The preventive measures are the substitution of wet scraping by using waterproof sandpapers and maintaining personal cleanliness and hygiene on the part of the painter.

(B) Zinc oxide has the advantage of being non-poisonous, and is not affected by fumes of sulphur. It is more resistant to the action of sea breeze than white lead, but for actual immersion in sea water, or in places subjected to severe spray of sea-water white lead is regarded as more efficient.

(C) Lithophone is another white paint, very similar in appearance to zinc oxide. It is extensively used, but mostly for interior work. It is a mixture of zinc sulphide and barytes, produced by a process of mutual precipitation. For interior work, it is as good as, and cheaper than zinc oxide, possesses good body and can be applied with great ease. However, it changes colour when exposed to daylight.

Within recent years two more white paints, viz. (1) Titanium white and (2) Antimony white have been introduced. Antimony white is sold under the proprietary name *Timonox*. Titanium white, manufactured in America goes under the name *Titanox*. Titanium white possesses intense opacity—even better than white lead, and is very invaluable as an undercoat to enamel, as it supplies a white body to the thin transparent film of enamel.

Red lead is the best for painting iron surfaces, to which it sticks well, and protects the metal.

Vehicle: The usual material is linseed oil. There are five grades of it.

(a) Raw linseed oil.
(b) Refined linseed oil.
(c) Pale boiled linseed oil.
(d) Dark or double boiled linseed oil.
(e) Stand oil.

Raw linseed oil is thin, but takes a long time to dry. It is, therefore, boiled, and during the process of boiling, a drier, such as litharge, is mixed. It then becomes thicker and darker. For delicate work, either raw linseed oil, which is thin, is used with driers; or poppy or nut oils, which are costly, may be used. Pale boiled or double boiled linseed oil is more suitable for painting plastered or metal surfaces. For wood work, especially if the original colour and grain are to be preserved, raw linseed oil is preferable. Double boiled linseed oil usually requires a thinning agent like turpentine. Stand oil was originally made by allowing raw linseed oil to stand exposed to sun until it thickened like honey. Now it is made by heat treatment. It dries slowly but forms a very tough and durable film with extremely good gloss.

Pigments: Pigments may be classified into five divisions:

(a) Natural earth colours, such as ochres, siennas, umbers, and iron oxides, (*hurmuz, geru, etc.*)

(b) Calcined colours, such as lamp black, Venetian red, Indian red, carbon black, ultra marine, red lead, etc.

(c) Precipitates, such as chrome yellow, Prussian blue, Brunswick green, etc.

(d) Lakes, prepared by staining barytes or china clay by means of dyes.

(e) Bronzes, i.e., metals, like aluminium, very finely ground.

Pigments are liable to fade by the bleaching action of the sun's rays. They are also subject to change of colour under the influence of sulphuretted hydrogen, moisture and heat. The pigments most readily affected by bright light are those produced by staining the bases with aniline dyes.

Driers: These are used in two varieties—liquid and paste. Liquid driers are compounds of certain metals, such as manganese, lead, cobalt, etc. dissolved in a volatile liquid. They are usually concentrated and must be used sparingly.

Paste driers are also compounds of the same metals mixed with a large percentage of inert material, such as barytes, whiting, etc., ground in linseed oil. Litharge, which is a compound of lead, is the most common drier in use, the proportion being a quarter lb. to a gallon of linseed oil. Zinc sulphate is also used as a drier, but it is costly. Next to litharge, red lead is popular. Driers

absorb oxygen from the air and impart it to the linseed oil, which, in consequence, sets hard, somewhat like cement. Driers, however, destroy the elasticity of the film, and should be used sparingly in the finishing coat; otherwise, the paint may peel off in scales.

Thinning Agents: The commonest thinning agent is turpentine. It serves as a solvent, makes the paint thinner, and facilitates its spreading evenly over the surface. It also helps penetration of porous surfaces, such as wood or plaster, but at the same time, reduces the gloss of the linseed oil. It should, therefore, be used most sparingly, particularly in the finishing coat. Turpentine rapidly evaporates, and while doing so, facilitates the drying of the oil.

There are a few substitutes for turpentine, mixed with a small quantity of turpentine, or scented, so as to have an odour like that of turpentine. Some of the substitutes have a higher penetrating value than genuine turpentine, but in other respects they are inferior to real turpentine.

Varnishes: A number of varieties of varnishes are obtainable each suited to a specific task.

Water varnishes are prepared from shellac, gum arabic, etc., dissolved in water. They are used for varnishing wall paper, maps, pictures, etc.

A spirit varnish is made by dissolving various gums and resins in methylated spirit. Shellac varnish and French polishes belong to this class.

Flatting varnish is an oil varnish with a high proportion of resin. It dries glossy, but is brittle, so it can be rubbed off by water proof sandpaper to give a perfectly smooth surface for the finishing coat.

Oil varnishes are of two kinds, those suitable for interior work and those for exterior work.

For inside work, white oil varnish is suitable for varnishing interior decoration and furniture. It is pale and almost colourless.

Extra pale French oil or coburg varnish is the palest varnish of the above class.

Superfine copal is suitable for interior, delicate coloured decoration.

For extenal work, the varnishes employed are termed oak, elastic copal, or body. The last named is very durable, though expensive and is very suitable for front doors and other much exposed parts.

A matt surface can be obtained by the use of encaustic or flat varnish, containing a little wax.

Enamels: Enamels, though a little costlier than paints, are durable, and thus economical in the long run. They dry more quickly to a hard, glossy surface, which may be washed down frequently without injuring either the colour or the gloss. They can be used both for inner and exposed positions. Before the application of an enamel, a coat of titanium white in pale boiled linseed oil at once improves the appearance.

Aluminium paint consists of very finely ground aluminium suspended in a medium composed of a quick drying spirit varnish or slow drying oil varnish according to the requirements. It protects iron and steel from corrosion far better than any other paint. It is, therefore, widely used for painting marine piers, oil storage tanks, etc. It resists heat to a certain extent, so it is applied to radiators, hot water pipes, etc. It is also good for its decorative effect.

Cellulose paints are a recent product. They are quite different from linseed oil paints and varnishes. The cellulose is made from nitro cotton. Inferior varnishes are made from celluloid sheets, photographic films, etc. In working, whereas ordinary paints harden by oxidation, cellulose paints harden by the process of evaporation of the agent used for thinning, and thus they dry very quickly. They can be more easily washed and cleaned, and possess greater hardness, smoothness, and flexibility. They stand extreme degrees of heat and cold, and are also unaffected by contact with hot water. Thus they are far superior to ordinary paints though appreciably more costly.

Knotting and Stopping Material: The best material for knotting is composed of pure shellac dissolved in methylated spirit. For stopping, Russian tallow or putty is used. The latter consists of two parts of whiting and one part of white lead mixed together in linseed oil and kneaded.

Workmanship: New wood, which requires, as a rule, four coats, should be knotted, primed and stopped. Knotting consists of applying two coats of shellac varnish over all the knots, and uneven surfaces. Then, a priming coat of paint is given. White lead, with a small proportion of red lead, is the best material for priming. Stopping, which consists of filling up nail holes, cracks, and other inequalities to bring the surface to a level, should be done after priming. Otherwise, the oil in the putty, used for stopping, will be absorbed by the wood and it will fall to powder.

Before re painting old painted work, it is necessary to scrub the surface and make it quite clean. Soap and water very much facilitate the work. Sugar soap is particularly satisfactory.

If the surface is very much pitted and blistered, it may be scorched by the flame of a stove, or by applying a paint solvent. The latter, however, should be used with caution. Some of them are inflammable, and others very caustic in action, so that even if the surface is washed clean, the subsequent coats of paint are likely to be damaged.

A new galvanised iron surface or a freshly cement plastered surface does not take paints readily. It may first be washed with dilute zinc sulphate or washing soda, and then paint applied.

A coat of sizing (glue mixed with water) is beneficial on plastered surfaces and brick work before applying a paint. It fills all the cracks and dents, and reduces suction. Otherwise, the oil in the paint would be sucked up and dry patches left on the surface.

Brushes: The success of painting depends as much upon good brushes as on paints. The brushes should be of bristles and not horse hair. The latter lack elasticity, wearing quality, and paint holding capacity, which bristles possess. Bristles can be distinguished by the fact that each bristle is split at ends. Further, horse hair curls up but bristles remain straight. A good brush should have springiness in the bristles. A round brush is considered best for painting.

There should be plenty of mixed paint on hand. If too much is mixed, it can be used as under coats elsewhere. Painting should be started from the top and should progress downwards. The paint should be finished over by drawing the brush along the entire length of small surfaces so that no breaks are

visible. The work should be done sufficiently fast so that one portion of a surface will not have dried before the next is started.

Only one third the length of the bristles should be immersed in the paint, and the excess paint should be removed by gently rubbing the brush against the inside surface of the pail. The brush should be held at right angles to the surface, and only the ends of the bristles should touch it.

Figs. 696 to 710 show the painter's tools.

A few Practical Hints on Painting: (1) Painting should not be done, as far as possible, in damp weather, and never on a damp surface.

(2) Painting should be avoided on a freshly plastered surface for at least six months. Otherwise, the alkalis in the plaster will bleach and discolour the paint.

(3) The surface to be ultimately painted should not be tarred. A coat of tar, even though very old, *bleeds* through the paint and spoils it. If it is unavoidable, two coats of good shellac knotting varnish should be applied after scraping the tarred surface, and then the paint should applied.

(4) Old brushes should be kept either in water or raw linseed oil, covering the bristles only.

Tel-panee: Simple oiling is most economical and also effective in protecting the exposed surface of woodwork. The process is this:

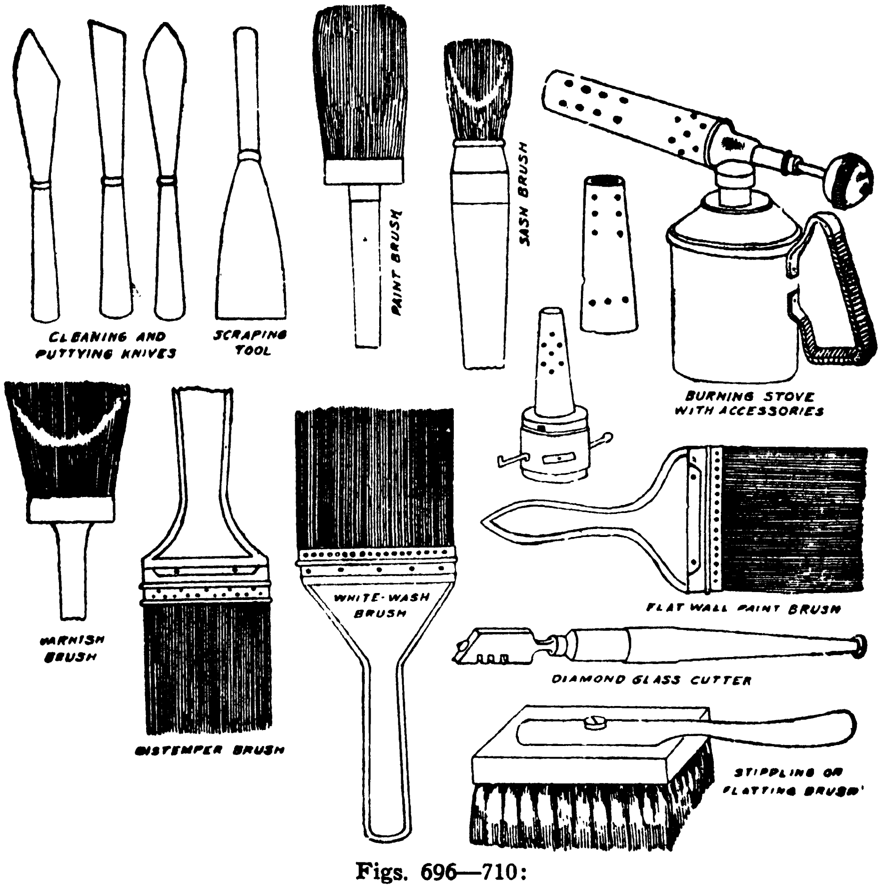
Take 3 kg. (3 lb.) of the best double boiled linseed oil, put one kg. (lb.) of beeswax into it and boil, stirring it till the wax melts and is dissolved. After it is cooled, add 1 kg. (one lb.) of turpentine, and apply with a rag in two coats. Finish with a sponge or rag dipped into water.

Spray Painting: Spray painting has so much advanced in recent years that it may be safely predicted that it may soon materially replace hand painting, even at expert hands. The advantages are:

(1) Work can be executed at a greater speed.

(2) The film of paint is evenly and more uniformly applied and is thus more durable.

(3) Two coats of spray are sufficient where three or even four of brush painting are required, thus causing a saving in both material and labour.



Figs. 696—710:
Painter's and glazier's tools.

(4) If the latest spraying plant is used, the mechanical agitator provided with it operates in a pressure chamber, constantly stirring the paint, and ensures *full* paint, without leaving sediment.

(5) With the spray pistol in the hands of an experienced painter, very artistic effects can be produced by the blending of different shades of colour, one into the other.

French Polishing: Oil varnishes are thick coloured and

obscure the original grain and colour. They are likely also to be scratched. French polish is free from all these defects.

The surface should first be sand-papered, then a coat of one of the filler compounds, given below, applied. A suitable colour or pigment may be added, if needed.

Filler Compounds:

(a) Whiting mixed with water or methylated spirit.

(b) Plaster of Paris in either water or raw linseed oil.

(c) Linseed oil, 3 lb., and beeswax 1 lb., boiled and applied sparingly with a rag dipped into turpentine.

When the filler coat dries up, the surface should be rubbed down with sandpaper. Apply as many coats of French polish as desired, prepared in the following way:

Dissolve 1·5 kg. (3 lb.) of black or light brown shellac *(chapda lakh)* in 12 bottles or 9 lit. (two gallons) of methylated spirit, keep well stoppered overnight, and add powders of gamboge (*Rewa chinika sira*) 125 gm. (¼ lb.), copal (*Chandras*) 125 gm., and Lobana (*Mogali Bedana*) 125 gm. (¼ lb.), and 12 gm. (one tola) of the crystals of the necessary colour, e. g., mahogany, light chrome, dark sesame, etc., stir well, and apply sparingly with a rag. It dries up in two or three minutes. The surface should then be rubbed lightly with *used* sandpaper. The latter should be very fine (0 to 00). It should then be wiped with a dry cloth, and the process repeated several times in succession until the surface assumes the desired degree of gloss.

Questions for Revision

(1) What essential elements go into the composition of a good paint? What is the function of turpentine in a paint?

(2) What are varnishes? What is the difference between a varnish and French Polish as regards the results?

(3) Write brief notes on:
(a) Bronzes, (b) Body of a base of paint, (c) Lakes, (d) Stains, (e) Matt paint, (f) Enamel.

(4) What is the difference between white lead, whiting and white lime? What are the adulterants commonly used in paints?

(5) Describe the process of French polishing. What filler compounds are used before French polishing and why?

FIRE PROTECTION : 19

THE word fire-proofing, as applied to buildings, is a misnomer. It is doubtful whether a structure could be really made fire-proof. All that is practicable and required is to make it fire-resisting and that, too, within reasonable limits. Time and temperature are the two most important factors.

The U.S. Bureau of Standards has classified structures, or component materials employed in structures, according as they function satisfactorily when subjected to the action of a conflagration for

(i) ½ hour (Temporary protection)
(ii) 2 hours (Normal protection)
(iii) 4 hours (Good protection)
(iv) 8 hours (Exceptionally good protection)

and further by actual observations has determined the following standards of intensity of fire:

TABLE NO. 35
STANDARDS OF INTENSITY OF FIRE

540° C (1,000° F) at	5 minutes
700° C (1,300° F) at	10 minutes
820° C (1,500° F) at	30 minutes
925° C (1,700° F) at	1 hour
1010° C (1,850° F) at	2 hours
1095° C (2,000° F) at	4 hours
1260° C (2,300° F) at	8 hours

For example, a fire-resisting floor would be defined as affording 4-hour protection, if during exposure to fire of from 540°C (1,000°F) to 1095°C (2,000°F), it sustained its full working load, did not develop cracks through which volumes of smoke could pass, nor became so hot on the upper side as to set fire to combustible substances resting on it.

It has also been laid down by the U.S. Bureau of Standards as a result of actual observations made of fires, that buildings having office or residential occupancies do not generally suffer from fire exceeding in effect and severity, the one-hour test exposure conditions, and exceptional fires in such buildings would probably never exceed the equivalent of 1½ hour standard exposure; further that mercantile, manufacturing, and warehouse types of buildings with more hazardous contents may develop fires which would equal in severity a two to four-hour period of standard test specifications.

Materials: Materials are either combustible or non-combustible. Combustible materials not only burn themselves, but in addition, increase the intensity of fire. The incombustible materials behave in a widely different manner under conditions of fire. Materials, whose function is to protect a building from fire, must be bad conductors of heat and must remain intact under the severest conditions.

Timber, though itself a combustible material, offers considerable resistance to fire. On exposure to fire, it first gets charred, and the high insulating value of the charred coating protects it from rapid combustion, even though the temperature may have risen to 500° C. After continued exposure, it is dehydrated, and the combustible volatile gases in it are liberated, which readily catch fire. To make a timber structure more fire-resistant, the following precautions are taken.

(1) The number of corners and the area of exposed surface should be reduced to a minimum. All sharp edges should be chamfered or rounded.

(2) Instead of employing a number of small-sized joists and floor beams, substantial sections, spaced wider apart, should be used. A solid wood floor of the same thickness is more resistant to fire.

(3) If a building has more than one floor, there should be as few floor openings as possible, and there should be no through openings in a multi-floor timber structure through which fire may spread from one floor to another. A through opening behaves as a chimney and induces draught.

(4) No oil paint or varnish should be used. Instead asbestos or magnesium silicate or ferrous-oxide paints should be employed for ceilings and partitions.

(5) Partitions of wood or bamboo laths, lime-plastered on the exposed faces, are quite safe.

(6) Fire stops should be provided in the floor and walls at close intervals.

Steel is an incombustible material, but as it conducts heat very readily, and expands and contracts, it is in some respects worse than wood. At 600° C, its yield stress is reduced to a third of its value at normal temperatures. Under intense heat, it becomes soft and expands, and with the application of cold water used for fire-extinguishing purposes it twists and contorts, leading possibly to the collapse of the structure. It is necessary, therefore, to protect all structural steel with a covering of some insulating material.

Protection of steel can be effected by covering the members completely with bricks, burnt clay blocks, terra cotta, or concrete —preferably breeze concrete.

Stone, more particularly granite, is liable to crack, splinter, and disintegrate. On exposure to fire, the differing expansion of individual crystals, of which it is composed, disrupts and disintegrates the material, so that after exposure to red heat it may readily be crumbled by hand. Sandstone is more fire-resisting than limestone.

Cement concrete, when exposed to fire, is first dehydrated, causing shrinkage cracks. At still higher temperatures, the lime is calcined and converted into quicklime, which may cause still further shrinkage, but when it is exposed to the action of water, it slakes with excessive expansion, and causes complete disintegration of the concrete. Sand markedly expands under intense heat and causes concrete to soften and crumble.

Concrete of slag from a blast furnace, or coke breeze, or crushed hard bricks is much safer, particularly if Portland Blast-furnace cement, which contains less free lime, is used.

Generally, light-weight, porous materials have a high insulating value.

Reinforced concrete structures are superior to steel-framed ones, since less steel is used, and that, too, well embedded and dispersed evenly throughout the mass concrete.

The ordinary lead or composition pipes are a source of danger, as they melt at a comparatively low temperature.

Glass has a low thermal conductivity, and the expansion is also very small. Sudden and extreme changes in temperature, however, result in fracture. When glass is reinforced with steel wire netting, e. g. in wire glass, its resistance is considerably increased, and its tendency to fracture with sudden changes in temperatures minimised.

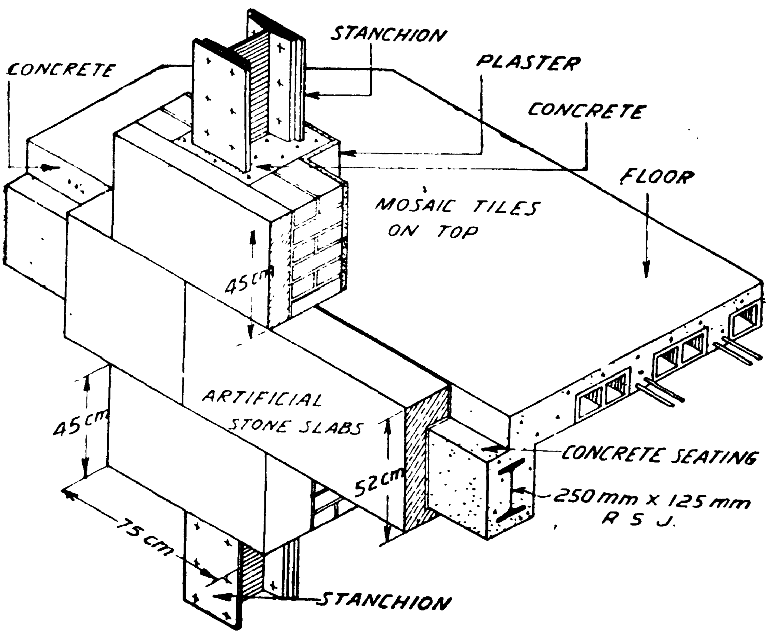


Fig. 711:

The steel stanchion and beam of this framed structure are encased in concrete.

Construction : The foregoing discussion of the behaviour of different materials when exposed to the blazing heat of fire and subsequent application of water will readily indicate the rough lines on which fire protection of buildings must be made.

As far as possible, combustible materials should not be employed in the construction of the structure.

If the construction is of solid bearing walls, bricks should be used in preference to stone. If it be a framed structure, R.C.C. frames are preferable to those of steel. If steel is employed, it should be embedded in concrete, or some other fire-resisting material, such as burnt clay blocks or terra cotta.

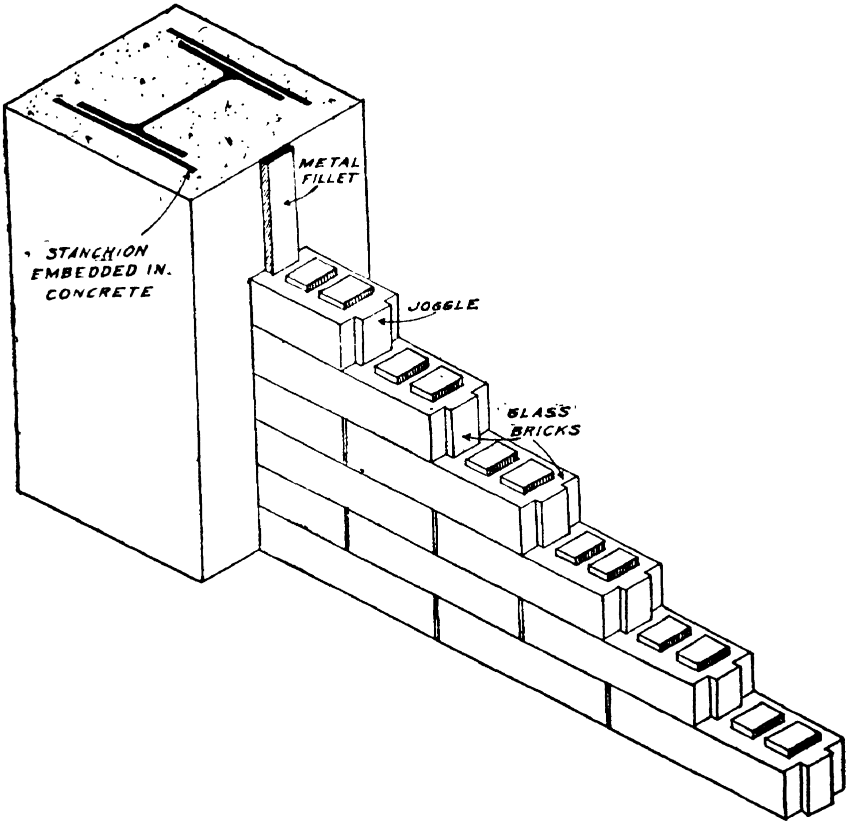
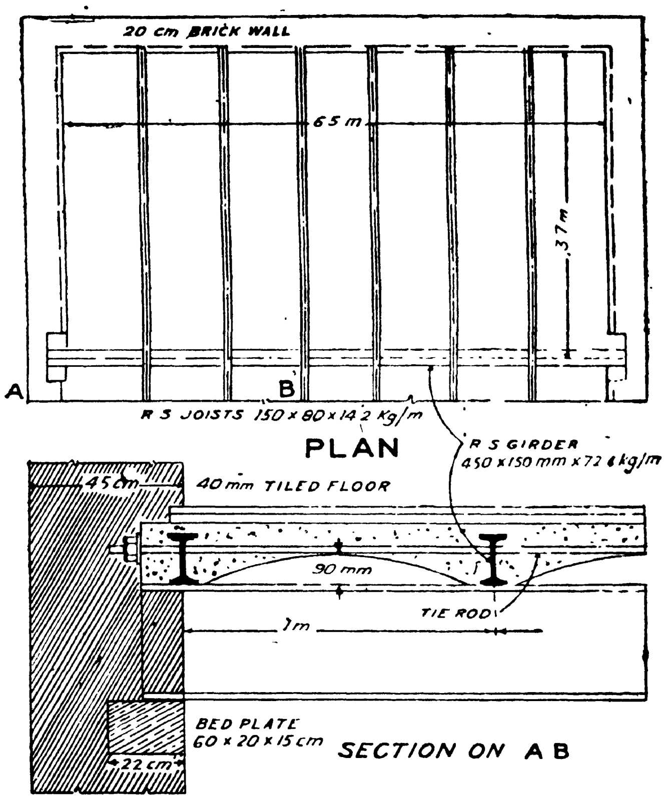


Fig. 712:
The steel stanchion is encased in concrete, and the partition wall is of solid glass bricks, which are fire-resisting.

Fig. 711 shows a steel stanchion and beam embedded in concrete.

Partition walls should similarly be of fire-resistant material such as R.C.C. or reinforced brick work, or hollow concrete, or burnt clay tiles, glass, or metal lath plastered over with cement mortar (See Fig. 712).

Floors and staircases are of great importance in considering fire hazards, since the prevention of vertical spread of fires greatly depends upon their location, character, and the fire resistance offered by them.



Figs. 713, 714:
Fire-resisting floor.

Figs. 713, 714 show concrete jack arch floor with steel joists embedded in concrete, which is fire-resistant.

Similar results are obtained by the combined use of R. C. and hollow burnt clay, concrete or terra cotta tiles.

Fig. 715 shows one such type. R. C. C. floors, with reinforcements of ordinary M. S. bars, XPM, Hy-rib, self-centering, Zilmil, B. R. C. Fabric, etc., which have already been referred to may be constructed.

As regards staircases, since they provide the only means of ascent to, or descent from the upper floors, these must, in all cases, be of fire-resisting material. Long flights of winders should be avoided. Stone should not be used except for the finish. Concrete staircases are very satisfactory. They should be cut off from the adjoining portions of the building by a fire-resisting wall, or wire glass partition, or other safe enclosure.

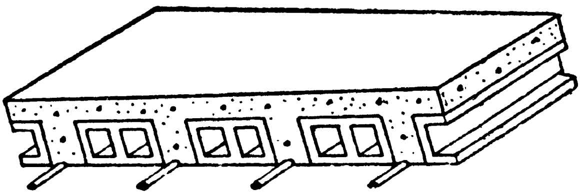


Fig. 715:
Fire-resisting floor with King hollow floor tiles.

Lift wells, though very convenient, if placed in the centre, are not desirable in that position from the point of view of fire-protection. All doors leading to the staircases or lifts should be of fire-resisting type.

Adequate means of escape must be provided from all floors according to the requirements of Municipal Building By-laws. Doors and windows should be of steel; wire-glass panes are now generally preferred for windows. Steel rolling shutters, for prevention of the spread of fire, are now being much more used for doorways and window openings.

Roofs should be of the flat type, and all the remarks made for floors apply to them. If pitched roofs are constructed, the trusses may be of R. C. C. or protected rigid steel, with asbestos cement sheet covering.

Acoustics is the science of sound as applied to buildings and includes in its scope, not only the design and construction of auditoriums, with proper acoustical conditions, and correction of acoustical faults in existing ones, but also absorption and dissipation of exterior and interior noises and insulation against sound, both air-borne and structure-borne.

It is now universally acknowledged that not only does noise adversely affect efficiency, but often does permanent harm by imposing a severe tax on the nervous system in the midst of the present-day strenuous business and industrial life.

Sound is a form of energy conveyed by vibrations of matter at the origin, and transmitted in all directions through any medium, whether solid, liquid, or gaseous. Sound travels in the air, at normal temperature of 20° C. at a speed of 343·8 m./sec. (1120 ft./sec.) in the form of spherical waves consisting of alternate compressions and rarefactions.

The velocity of sound in water is 4 times that in air, about 10 times in wood, 12 times in brick, and 15 times in steel.

There are three characteristics of audible sound:

1. Pitch.
2. Loudness.
3. Tone quality.

The pitch of a sound is the frequency of its vibrations, i.e., the number of vibrations per second. It is, therefore, the velocity of sound divided by the wave-length.

The highest audible pitch of sound, such as that of a shrill whistle, has a frequency of 20,000 cycles per second, while the lower audible pitch of sound (a whisper) has a frequency of 20 cycles per second.

The loudness is the strength of the sensation received through the ear. ~~It depends~~ upon the amount of energy in the sound waves entering the ear.

Tone quality of sound is the characteristic which distinguishes it from another sound of the same loudness and pitch. Most sounds are composite, i.e., consisting of the main fundamental note and its overtones. The overtones, having a frequency which is an exact multiple of that of the fundamental, are called *harmonics*. pitch & duration of sound

High frequency overtones contribute the quality of *brilliance* to music and *sibilance* to speech, whereas the lower frequencies in both cases contribute the characteristic of *timbre*.

The laws of sound propagation, reflection, absorption, and refraction conform to optical laws. For instance, the angle of incidence is equal to that of reflection. The amount reflected may be as much as 99.99 per cent, depending upon the hardness and rigidity of the surface upon which the sound waves strike.

Measurements of Loudness: The sensitivity of human ear varies throughout the range of frequency. It is low at lower frequencies but increases with increase in frequency up to a maximum of 1000 cycles per second, after which it falls. This means that the same mechanical energy put into sounds of different frequencies will not cause the same sensation of loudness to the ear. Hence two different units for expressing the energy of a sound are employed. The one for mechanical energy of vibrations, or sound is *decibel* and the other, for measuring loudness sensation in the ear is the *phon*. The latter is the smallest change in loudness of medium frequency which can be detected by the ear. Decibel is thus a unit of energy measured on an instrument while phon is that of loudness as perceived by the ear.

For comparing loudness by the ear, i.e., based on phon, a very convenient scale is used from 0 phon, which is a whisper on the threshold of audibility, to 120 phons at the extreme end, which is a sound which just causes painful sensation to the ear, such as an aeroplane engine at ten ft. distance. Public speeches have usually a loudness of 40 to 50 phons and loudspeakers in cinema theatres come up to 70 to 75 phons.

This scale is given in Table No. 36.

As regards frequency, human ear cannot hear sounds of less than 20 cycles per second. The upper limit is 15000 to 20,000 c/s. but it decreases with age.

Absorption of Sound: If sound waves impinge upon a

TABLE NO. 36

SCALE OF INTENSITY OF LOUDNESS IN PHONS AS PERCEIVED BY THE HUMAN EAR

Locality	Loudness in Phons	Kind of Noise
	120	Threshold of pain; Aeroplane engine at 3 m. (10 ft.)
Boiler workshop Train in tunnel	110	Shrill whistle
Aeroplane cabin	100	Pneumatic drill; Motor bike.
Very noisy street	90	Jazz music; motor horns.
Bazar	80	Trams; Accelerating Diesel bus.
Talkie theatre	70	Gramophone at village bus stand, Radio speech. Group *Bhajan*.
Quiet street. Room with ordinary conversation. Train, windows closed	60	Normal speaking.
Quiet office and restaurant	50	Household talk.
Quiet suburban street	40	Low radio music.
	30	Average domestic noise.
	20	Whispering.
	10	Rustle of leaves in slight breeze.
	0	Threshold of audibility.

resilient and porous surface, considerable energy will be dissipated as heat in passing through its pores, and the absorption would be relatively high. As an open window does not interfere with free passage of sound, it is considered as 100 per cent absorbent, and the capacity of every material to absorb sound is referred to this standard.

The coefficients of absorption in Table No. 37 give the number of *open window units* of absorption per sq. m. of material.

TABLE NO. 37

COEFFICIENTS OF ABSORPTION OF SOUND IN DIFFERENT MATERIALS

Material	Frequencies of sound waves	
	512 c.p.s.	2048 c.p.s.
(a) To be calculated on 1 sq. m. basis		
Concrete, marble, water surfaces (e.g. in swimming pools)	0.01	0.02
Plaster	0.02	0.03
Brick masonry in cement mortar	0.02	0.02
Glass of normal thickness	0.03	0.02
Linoleum	0.03	0.04
Wood	0.10	0.08
Cotton cloth—plain	0.13	0.32
Carpet—5 mm. thick	0.15	0.52
Coir	0.17	0.32
Curtain	0.23	0.30
Openings in theatres	0.25—0.40	—
Acoustic plaster	0.25—0.35	—
Oil paintings including frames ...	0.28	—
Velour	0.35	0.38
Window and grill openings ...	0.50	0.50
(b) To be calculated per number		
Wooden chair	0.01	—
Chair with thin cushioning	0.02	0.02
Chair with leather cushion	0.18	0.07
Chair with velour cushion	0.28	0.34
Audience per person	0.44	0.46

Note 1:—A few absorption coefficients for a pitch of 2048 cs./sec. are also given in the above table just to show that absorption varies as the pitch. The coefficients generally used for acoustic analysis are for 512 cs./sec. as this is the average pitch of male and female singers.

Note 2:—As a general rule, material having surface porosity, even though thin, like a thin carpet is good for absorbing high frequencies. On the other hand, for absorption of low frequencies, the material should be thick irrespective of surface porosity.

The sound absorption coefficient is not the same for different pitches or frequencies as will be seen from Table No. 37.

An ideal material for sound absorption for use for lining walls, floors and ceilings should possess the following qualities.

(1) It should have a high coefficient of sound absorption for economy.

(2) It should be fire-resistant, possessing structural strength, not subject to decay by atmospheric influences, durable, heat-insulating, non-hygroscopic, not liable to be attacked by insects and vermin, and capable of being easily handled, cut, worked, bent and fixed.

Reverberation: A sound produced in an enclosed space, travelling outwards from the source is first amplified by the reflection on the surfaces of walls, floor and ceiling, but as it is inter-reflected from one surface to another it is soon partially absorbed, and as a result, it gradually decays or fades, until after some interval of time becomes inaudible. This is called *reverberation*. If a room is furnished and draped, the effect is felt sooner.

The period of reverberation varies directly as the dimensions of the room and inversely as the absorption present.

Sabine has proved that the reverberation time, T, in seconds in a room

$$= \frac{4 \times 14}{c} \cdot \frac{V}{aS}$$

where V = volume of room in m^3
c = velocity of sound in air
= $343 \cdot 8$ m/sec.
a = co-efficient of absorption
S = area of absorbing surface.

This is approximately given as

$$T = \frac{0.16\ V}{aS}$$

Eyring has given the following formula:

$$T = -\frac{4 \times 14}{c} \; \frac{V}{S \log_e(1 - a)}$$

This is more exact formula to calculate the time of reverberation. For values of $a < 0 \cdot 2$ the term $\log_e (1 - a)$ can be approximately written as a.

For rooms where the different materials having a wide range of co-efficients of absorption are used, Millington has modified the above formula as:

$$T = 0.16 \frac{V}{\Sigma S \log_e (1 - a)}$$

Obviously in an open air theatre, there is no reverberation.

Correct reverberation improves and ameliorates sound. This is particularly desirable in churches and lecture halls. If the reverberation time is excessively long, it leads to overlapping of consecutive syllables with loss of intelligibility. For, before the sound of the first syllable dies or fades to a certain limit, that of the next is mixed with it. If on the other hand, it is too short, it produces an effect of deadness with loss of brilliance. This correct reverberation is called *optimum reverberation.* wrong.

From Table No. 37 we have seen that the absorbing power of an auditorium varies as the pitch. The higher the pitch, the greater is the absorbing power. Thus an auditorium designed for musical concert with high tones, such as those of a violin, will prove a failure it is used for public speech.

Again, it is seen from the same table that a single person of audience provides such a large absorption viz., 4.7 units (equivalent to 44 sq. m. or 470 sq. ft. of concrete floor). This makes a very great difference between a theatre full and a theatre empty.

TABLE NO. 38

Type of building	Optimum reverberation by Sabine formula	Audience factor for design purposes
Law Courts, Conference and Committee Rooms	1 to 1.5 secs.	one-third
Parliament House, Council Chambers	1 to 1.5 "	quorum
Public Lecture Hall	1.5 to 2 "	one-third
Music Concert Hall	1.6 to 2 "	full
Cinema Theatres	1.3 "	two-thirds
Churches	1.8 to 3 "	two-thirds
Very large Halls	2 to 3 "	two-thirds

It is therefore impossible, except by resorting to adjustable absorbents to provide optimum reverberation if the same audi-

torium is to be used for different purposes. The modern trends are to use an auditorium for widely varying purposes. Hence some compromise has to be made by allotting some average values to the audience factor as shown in Table No. 38.

As a rule, shorter optimum reverberation is required for reproduced sound than for original note due to the fact that some reverberation is already introduced in it at the time of recording.

Echo is caused by strong reflected sounds arriving later than $t = 0.05 \pm 0.1$ second after the production of the original sound.

As the velocity of sound is 343.8 m./sec. (1120 ft./sec.), the difference in the length of the path of the direct sound and reflected sound must be at least $l = 17 \pm 3$ m. $\left(\frac{1120}{15} = 75 \text{ ft.}\right)$ to produce a definite echo. It is objectionable in buildings designed as auditoriums, and is caused by unsuitable shape of the building and wrong location of the origin of sound.

Interference is caused by the coincidence of the instant of compression in the direct wave with the instant of rarefaction in the reflected wave.

Resonance under proper control is good, but if only a few notes of certain frequencies resonate, the amplification is out of proportion and the result is that correct balance of tone is upset.

Acoustical Analysis and Treatment for Correction: The objection of acoustical analysis is to check the existing adsorption, and if it is found inadequate, to apply correction to it by suitable measures. The procedure is as follows:

(1) Calculate the total volume by adding up the volume of the main void, that of the space below the balcony, and that between the floor of the balcony and the bottom of the ceiling, if there is only one balcony, or volumes between different tiers of balconies, if there are more than one.

(2) Measure areas of surfaces such as floor, ceiling, walls, etc., separately having different absorption coefficients.

(3) Multiply each of these areas by its corresponding appropriate absorption coefficient, which would give the absorption in ft. units.

(4) Add these units together.

(5) Compare this total absorption with that required for optimum reverberation calculated by Sabine formula.

(6) If the absorption provided is found insufficient, make

(1) By direct passage of air-waves through openings, such as not only doors, windows, ventilators, etc., but also through key holes, chinks in door shutters and partitions, ducts, pipes, conduits, etc.

(2) By vibrations of the dividing medium itself as a diaphragm, which by its motion reproduces sound-waves on the farther side.

(3) By direct transmission of elastic wave motion through the dividing medium which imparts to the air at the farther side a wave motion exactly timed to that of the origin.

Transmission through the first is the greatest of all and can be prevented by first isolating noises, and then making these parts reasonably air-tight.

The next important way of transmission is (2) above, and can be remedied by making the partitions or dividing walls massive and rigid.

The third source of transmission is negligible.

Principles Underlying Insulation of Sound: The object of insulation is to dissipate sound energy, and convert it into heat energy.

Absorption of sound and its conversion into heat is increased by providing a laminated construction with the inner layer very absorbent of sound.

The sound energy absorbed as mechanical energy is increased by using heavy massive construction.

Diaphragm-like vibrations can be minimised by adopting a rigid construction.

Measurement of the Insulating Capacity of Materials: We have seen before that the loudness of a sound is measured on a scale of 120 sensation units. Insulation is measured in *reduction* sensation units. Thus, exceptionally good insulation or sound-deadening means a reduction of 80 to 100 sensation units, and very bad insulation means a reduction of 0 to 40 sensation units. 50 to 60 units reduction indicates a fairly good, or good insulating medium; and 70 to 80, very good.

Fig. 716 shows a section of a composite partition showing best sound insulation under National Physical Laboratory tests, in which the central medium is a grass quilt, on both sides of which boards of compressed straw are fixed and plastered with cement mortar. It weighs 81 kg./m.^{2} and still gives as high

an insulation as equivalent to 75 sensation reduction units. If glass silk is substituted for eel grass, the partition will be equally efficient.

Table No. 40 gives the results of different materials tested by the Bureau of Standards, U.S.A., and the Swedish Government Testing Institute.

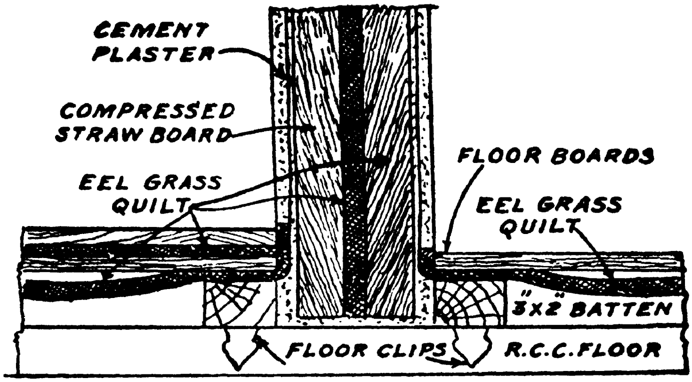


Fig. 716:
An ideal partition and floor from the point of view of sound-proofing.

TABLE NO. 40
WALLS AND PARTITIONS

No.	Type of Panel and Material	Thickness	Average Reduction Factor in Sensation Units
I	Wooden framework with the following boards fixed on one side		
	Cane fibre board	6 mm.	19.5
	Wood fibre board	6 mm.	20.3
	Wood fibre board	8 mm.	21.8
	Galvanised iron	.03	28.3
	Plate glass	6 mm.	32.7
	Lead	6 mm.	34.4
II	Framework of wooden studs 100 × 50 mm. at 45 cm. centre to centre with the following boards or plaster fixed on both sides		
	Asbestos millboard	12 mm.	31.6

No.	Type of Panel and Material	Thickness	Average Reduction Factor in Sensation Units
	Gypsum board		35.8
	Gypsum plaster (two coats on wood lath)		43.7
	Lime on wood lath sand-faced		50.5
	Gypsum rendered and float finished plaster on XPM		51.7
	Gypsum rendered		52.1
	Lime on wood lath rendered		52.7
	Lime on XPM rendered		57.2
	Lime on wire netting, 3 coats smooth		58.7
	Lime on XPM rendered and floated		62.9
III	Gypsum hollow tiles 75 × 30 × 4.6 cm. circular core built up to form 4.6 cm. wall smooth finished with lime plaster 2 coats		35.8
	with gypsum plaster 2 coats		43.1
	with gypsum plaster in two rows with 4 cm. cavity between		52.6
IV	18 mm. M. S. channel studs with XPM sheets wired on both sides Gypsum plaster on both sides 50 mm. thick	57 mm.	42.1
	Gypsum plaster on 25 mm. layer of hairfelt between	70 mm.	48.5
	Gypsum plaster on cane fibre board with 50 mm. air space.	125 mm.	54.1
V	Hollow clay tiles 3 cells 7·6 cm. × 30 cm. × 30 cm. with 2 coats lime plaster	114 mm.	38.5
	with two coats gypsum plaster	114 mm.	39.1
	with only floated coat of gypsum plaster	114 mm.	45.4
	with 3 cells 15 cm. × 30 cm. × 30 cm.	190 mm.	47.1
	with 6 cells 15 cm. × 30 cm. × 30 cm.	190 mm.	49.2
VI	Brickwork on edge 10 cm. thick including 2 coats of lime smooth plaster	100 mm.	43.1

No.	Type of Panel and Material	Thickness	Average Reduction Factor in Sensation Units
	2 coats of gypsum plaster	100 mm.	46.4
	Brickwork ½ brick thick with gypsum plaster	150 mm.	48.7
	with 19 cm. brick	240 mm.	53.6
	with good workmanship	240 mm.	56.7
VII	10 cm. × 5 cm. wooden studs at 40 cm. c. to c. with quilted fibre on one side and furring strips, wood lath and 3 coats of gypsum plaster on the other	12 mm.	48.2
VIII	10 cm. × 5 cm. × 30 cm. hollow clay tiles with 5 cm. × 2.5 cm. furring strips at 40 cm. c. to c. with building paper, metal lath, and gypsum plaster	19 cm.	57.5
	with 12 mm wood fibre board and gypsum plaster	17 cm.	60.7
IX	5 cm. tongued and grooved wooden board in centre, 24 mm. air space on both sides, and 12 mm. fibre boards on outside	12 cm.	67.5
X	With additional 12 mm. plaster on the fibre boards	14 cm.	78.0

Floors: The important methods for prevention of sound transmission through floors employ one of the following types of construction:

(1) A floating floor isoated from the walls. (Fig. 716).

(2) An isolated material of non-homogeneous nature between the floor covering and the floor proper.

(3) A solid rigid floor.

(4) A suspended ceiling.

The sound transmitted by walls and partitions is the noise from one room to adjoining rooms, but in the case of floors, it may consist, in addition, of the mechanical vibrations (tapping or footsteps, etc.) transmitted to the room below.

Some Practical Suggestions About Sound Insulation: (1) The increase in insulation of a solid wall is slow in proportion to

TABLE NO. 41

FLOORS

Type of Floor	Covering and Finish on Top	Finish of the Ceiling Below	Average Reduction Factor in Sensation Units
100 mm. × 50 mm. wooden joists at 40 cm. c. to c.	10 mm. wooden boards on 12 mm. rough boards	Plaster on wood lath	47.1
	10 mm. boards on 12 mm. rough boards, the latter again on 50 mm. × 25 mm. strips nailed on 25 mm. fibre boards	Plaster on wood lath	57.8
15 cm. — 4-cell hollow clay tiles	50 mm. of cinder concrete and 25 mm. of cement concrete floor	Gypsum plaster	48.2
10 cm. R.C.C. floor	10 mm. boards on rough boards in 50 mm. × 25 mm. strips	12 mm. wood fibre board plastered	61.1
R. C. C. floor with 100 mm. × 300 mm. × 300 mm. hollow clay tiles at 50 cm. c. to c.	— Do —	— Do —	65.6
R. C. C. hollow clay tile floor on 100 mm. × 50 mm. wooden joists at 40 cm. c. to c.	In 50 mm. wood fibre board	— Do —	66.3
	— Do —	Suspended ceiling of 25 mm. fibre board plaster	70.0

the increase in its thickness. Hence, it is not economical to increase the thickness beyond a certain limit.

(2) On the other hand, if the material is of porous, flexible nature like hair-felt, its insulation is proportional to its thickness.

(3) Laminated construction is the most effective when the several layers are free from all connections and each is on its own separate foundation.

(4) Fillers used in air spaces are detrimental to sound insulation, as they provide a bridge between the separated surfaces.

(5) If, instead of one 20 cm. (9 inch) brick wall, two separate walls, each 10 cm. ($4\frac{1}{2}''$) thick are built, the latter will have an 80 per cent increase in insulation without increase in weight and with a little increase in cost.

(6) For good insulation, doors should be made air-tight.

(7) A steel plate solid door is more efficient than a double wall, hollow *cold storage* type door.

(8) Smaller glass panes, which make window shutters stiffer are more advantageous than larger ones.

(9) Solid glass has a higher insulating value than even a thicker flexible triplex glass.

(10) Double glazing considerably improves insulation.

A Few Suggestions For Acoustic Designs of Auditoria For Different Purposes

General Principles for the Guidance of the Designer: (1) A shorter optimum reverberation period is required for reproduced sound such as of gramophone records, sound films, etc. than that for original one. This may be due to the fact that there is already some reverberation present introduced at the time of recording.

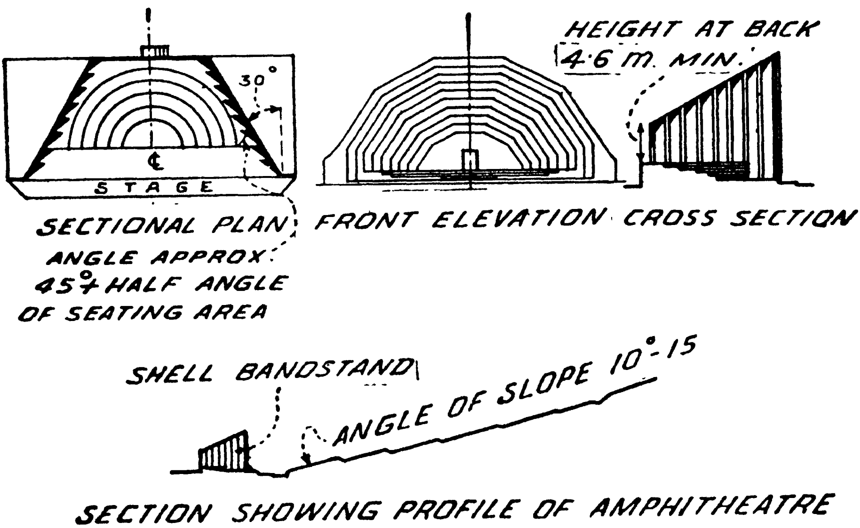
(2) For direct orchestral music, the reverberation time required is about 15% longer than that for unaided speech, and for choral music it is about 40% longer. This is because that in music, overlapping of sound is desirable, especially when the succeeding sounds are harmonious, whereas, in speech excessive reverberation causes a blurring effect. For this reason, music halls should have at least 60 cu. m. (200 cu. ft.) per seat capacity.

(3) The absorption coefficient of soft plaster is 3 to 4 times that of hard plaster. The coefficient of distemper is higher than

that for paint. Wood panelling has a fairly high coefficient at lower frequency where reverberation is greater. An audience absorbs 70 to 80% as compared with 100% of open window. Next best is cushioned seat and back of chair. Thus in a cinema theatre, if carpets and upholstered seats are provided, the number of audience is not of importance, whereas in churches and halls where bare wooden seats are provided, it assumes great significance.

(4) In planning auditoria for volume, height is of greater importance than either length or breadth. A small increase in height effects considerable increase in the volume.

(5) While providing absorption, it should be considered that the reverberation time is not uniform throughout the auditorium. If the average period is 1·3 secs., it may be 1·5 in the main void, 1·2 in balconies and perhaps even less below the balcony.



Figs. 717—720:
Hollywood bowl (Open air theatre).

We shall now consider a few practical cases.

(1) **Open Air Theatre:** In this case as there are no barriers of walls there is no reverberation. What is required is a hard reflecting surface on the back side, of the shape of a shell to form a hood to strengthen and direct the sound forward towards the

audience, seated on a raised sloping ground in front to command also good sight lines.

An excellent example of an open air theatre is that of the Hollywood Bowl sketched in plan, elevation and sections in Figs. 717—720 which caters for an audience of 20,000.

The direction of wind at the time of the programme is an important factor in either helping or obstructing the passage of sound.

(2) **Public Lecture Halls:** Here the optimum reverberation time is that given by Sabine's formula less 10 to 15 per cent according to the size of the hall. If loud-speakers are employed, no deduction need be made. At any rate, the time should not exceed 1·5 seconds even for large halls. The volume per seat should be between 3 and 4 cu. m. (100 and 130 c. ft.) Hard reflecting surfaces on the back and around the dais, slightly inclined outwards and rear distant wall facing the dais treated with absorbing material are the requirements.

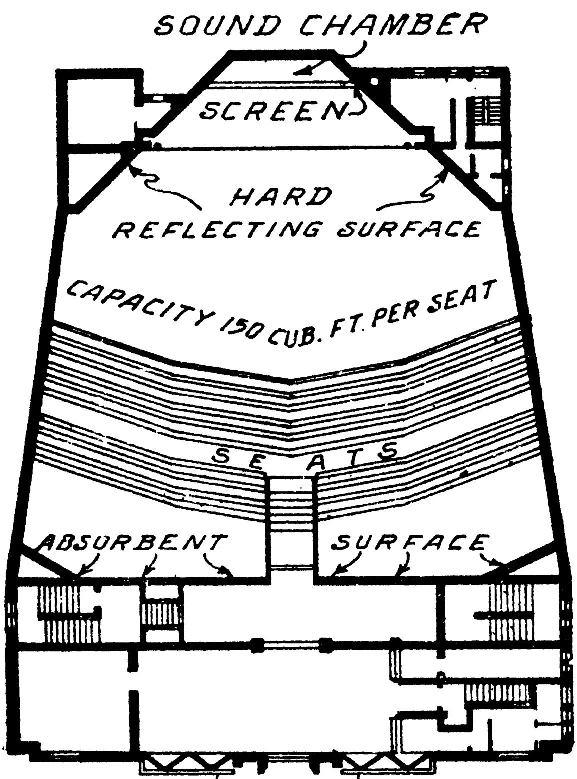
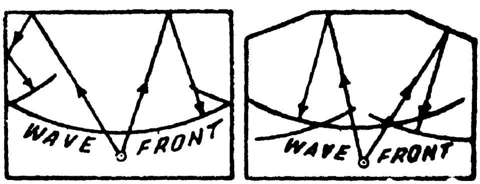


Fig. 721:
A plan of a typical cinema theatre.

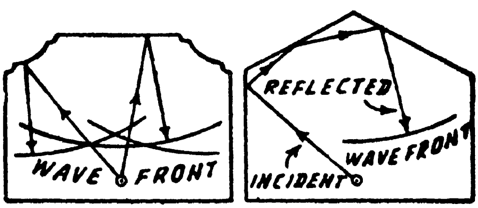
(3) **Concert Hall:** The volume per seat should be between 4·5 and 6 cu. m. (150

and 200 cu. ft.) or more for large houses. There should be hard reflecting surfaces about the platform, flat ceiling, lined with reflecting material, and distant walls absorbent. Avoid reflection back to the platform by breaking up the surface of the rear walls into panels, using absorbing material. The floor and seating area should be absorbent. The reverberation time should be at least 1·5 seconds. Wood surfaces used for lining resonate and enrich musical notes.

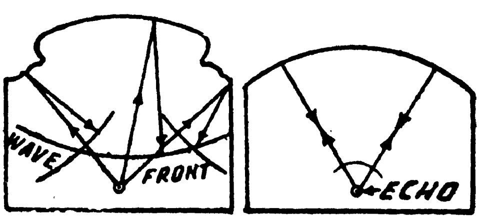
(4) **Cinema Theatres for Sound Films:** *Shape* and *Proportion:* A fan shape in plan with diverging side walls has been found by experience to be the best. However, there are a number of oblong rectangular theatres with excellent acoustic conditions. A fan shape also affords good sight lines for the spectators, and



Figs. 722, 723



Figs. 724, 725



Figs. 726, 727

distributes sound energy equitably from the loud-speakers behind the screen. Parallel walls are likely to cause flutter. The ceiling should be flat and should have a slight upward slope from the proscenium towards the rear. The proportion of height, width and length should be approximately as 1:2:3. Fig. 721 shows a very suitable shape for a sound film theatre. The surfaces near the source of sound should be of polished, hard, reflecting

material, and those of distant walls of absorbent material. Figs. 722—727 show cross sections of some common auditoria, in which the fronts of reflecting waves are plotted. Generally speaking, types shown in Figs. 722 and 724 give very good results. The type in Fig. 725 is susceptible to cause echoes unless the underside of the ceiling is of a highly absorbing material. In types shown in Figs. 726 and 727, the echoes produced are bad, and are very difficult to cure.

As a general rule, curved surfaces should be scrupulously avoided, unless they are lined with good sound-absorbing material. If the radius of a curved ceiling is less than twice the height of the auditorium, troublesome echoes will be formed.

Volume: The volume for a sound film theatre should be between 4 and 4·5 cu. m. (130 and 150 c. ft.) per seat.

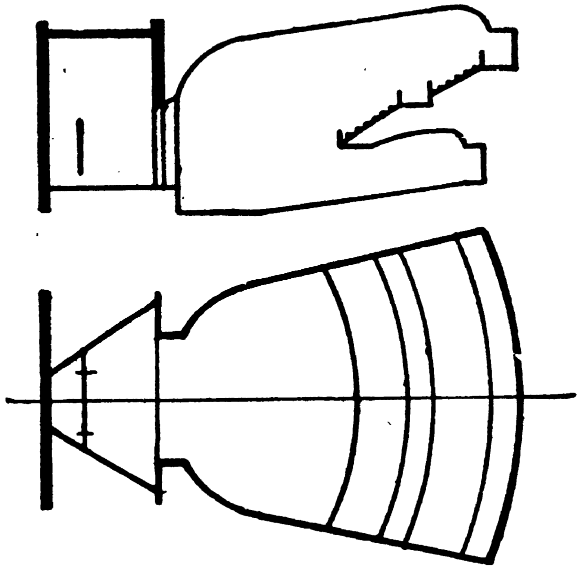
Balconies: The overhang of a balcony is determined by the height of the balcony soffit and the sight line from the rearmost seats. The height below the soffit of the balcony should be high enough to admit sufficient sound energy to the rearmost seats. This is particularly to be kept in mind as here the soft surfaced walls absorb a large amount of sound.

An echo must be prevented in a sound film auditorium at any cost by (1) avoiding curves as mentioned above, (2) using absorbing materials on the rear walls, the surface of which may be further broken up by forming half-round pilasters at intervals projecting 8 to 10 cm. (3 to 4 in.) with vertical lines of fluting on their faces.

Reverberation Time: The reverberation time should be 1·2 to 1·3 seconds according to the size of normal theatres accommodating up to 1500 seats. If the volume-seat relation is maintained while planning, the rear walls and part of side walls are lined with absorbing materials, there should be no difficulty. But if it is found that the acoustic conditions are not satisfactory, after the theatre is completed, analysis of absorption should be made and the deficiency made good by first using carpet runners between rows of seats, then upholstering seats with soft material, and finally using fibre board panelling on side walls. The entire stage house should be reflecting especially the back wall which should preferably be lined with glazed bricks or tiles. If an orchestral pit is provided, its floor also should be of polished resonating wood.

Figs. 728, 729 show a plan and a longitudinal section of a typical good design of a cinema theatre, embodying all the above requirements.

If in the case of an existing theatre, the acoustic conditions are not satisfactory, and if the acoustic analysis made confirms it, the exact position where the additional absorption is required may be determined by first using folded heavy cloth curtains against the rear wall and then at different parts of the side walls, and the effect should be watched every time, and the position where the curtain gives the most satisfactory result should be finally fixed, and a suitable economic absorption treatment provided in that part.



Figs. 728, 729:
Longitudinal section and plan of a typical sound film theatre.

Common acoustic defects of cinema theatres, their causes, and the remedies to prevent or cure them are given in Table No. 39.

(5) **Multi-purpose Theatres:** Modern tendency is to use the same hall for multiple purposes, such as public speeches, musical concerts, dances, drama performances, as well as travelling talkie films. This makes the acoustic problem very difficult. It is practically impossible to provide acoustic conditions which will be consistently satisfactory for these manifold uses. A compromise has, therefore, to be made. The only way is to provide adjustable absorbents to suit the particular purpose as is done at great cost in broadcasting studios described below.

(6) **Radio Broadcasting Studios:** The requirements are: perfect noise-insulation, and variable reverberation. To accomplish the first, floors, walls, and ceiling must be of rigid, massive construction to minimise transmission of sound by diaphragm-like vibrations and to reduce resonant reflection to a minimum.

Variable reverberation time is very important. For, not only different reverberation times are required for each programme, but also for each item in it, such as speech, low and high frequency music, etc. This is effected by several means: (1) A number of studio rooms, each with different absorption suited to a particular type of broadcast are provided. (2) In some studios on the continent, studio walls are fitted with hinged shutters each having different absorption treatment on either face. By means of a gear, one or any number of these can be turned to present any degree of absorption at will. (3) In Hamburg (Germany) by means of a movable partition, the volume of the studio room can be varied to give the desired reverberation time. (4) B. B. C., London, uses heavy woollen folded drapes arranged horizontally near the ceiling, which can be drawn across the reflecting ceiling to adjust reverberation time to any extent from 1 to 3.

Shape and Proportion: The National Broadcasting Corporation of America advocates a proportion of height: width: length as 2:3:5. In B. B. C. the length recommended is 25 to 75 per cent in excess of the width and a considerable height. As regards the shape, a rectangular shape with flat ceiling is invariably prescribed. The reverberation time should be correct in relation to the volume and absorbing surfaces, to give a frequency characteristic of the variety of broadcast.

If reverberation is found insufficient with all the above measures, it may be strengthened by providing an artificial echo designed with mathematical accuracy in a special echo room where the sound from the microphone in front of the artistes is carried and strengthened by mixing it with its echo.

For a radio broadcasting station, the studio rooms must be reasonably air-tight, ventilated with conditioned air supplied through silenced grilles.

A number of studio rooms are actually required according to the importance of the station, viz. studios for performances of artistes with microphones, in front, rooms for rehearsal, listening rooms—one attached to every studio room, sound-insulated

from the studio and provided with a glass window through which the station director or his assistant can see the performances, "silence rooms" for use during announcement of the items, etc.

The sequence of the general arrangement for a simple broadcasting station is: microphone—amplifier—transmission line—power amplifier—transmitter—aerial. This is shown in a flow diagram in Fig. 730. That at the receiving end is: aerial—radio receiving s adio frequency amplifier—detector—audio frequency amp..er—loud speaker).

Questions for Revision on Chapter XIX

(1) What are the standards of fire protection of buildings?

(2) Timber is said to be more fire-resistant than steel. Explain this. How can the fire-resisting properties of timber be best utilised i.e. how can it be made more fire-resisting?

(3) How do the following materials behave during a conflagration? Glass, Stone (and its varieties), Sand, Concrete, Blast furnace slag, Brick, Clay.

(4) Why is a staircase the most important member of a building structure during a fire hazard? How can it be made fire-resisting?

Questions for Revision on Chapter XX

(1) How is loudness of sound measured? What are the common units?

(2) Define the following:—Pitch frequency, Reverberation, Resonance, Echo, Reflecting surface, Acoustic plaster.

(3) What is meant by sound absorbing capacity of a material? Why is the coefficient at c_4 (512 cycles/sec.) used for rough calculations?

(4) A small cinema theatre of 3000 cu.m. volume, designed for 640 seats has the following interior surfaces:—

Coir matting: 70 sq. m. Varnished w n surface: 300 sq. m. Plaster on lath ceiling: 220 sq.m. h / curtains: 60 sq.m. Glass windows: 46 sq. m. Ventilating grilles: 10 sq. m. Concrete floor: 600 sq.m.

Calculate the time of reverberation by Sabine's formula for the theatre (i) empty and (ii) full. Take half the number of seats as fully upholstered and half of plywood.

(5) What causes an echo and how can it be prevented?

(6) What do you understand by optimum reverberation?

NEW MATERIALS AND PRACTICES* : 21

A FEW new materials have recently come into use, either on account of their superiority, less cost or as substitutes for traditional materials when the latter are in short supply, and with them new methods have arisen. Most of these have been dealt with in the text of this volume. However, a few additional ones are briefly described here.

1. **Concrete:** Cement concrete of normal density weighs 2200 to 2400 kg./m.^{3} (140 to 150 lbs./ft.^{3}) It is very strong in compression. But there are many uses where so much strength is not required, and where its heavy weight is a disadvantage. Besides, it transmits sound, does not hold a nail or a screw, and is inefficient in respect of thermal insulation.

Light-weight concretes have, therefore, been developed in which most of these deficiencies are overcome. A light-weight concrete is concrete which weighs about 1555 kg./m.^{3} (100 lb./m.^{3}) or less. There are three types:

(i) Light weight concrete made of light weight aggregates.
(ii) No fines concrete, and
(iii) Aerated, or cellular concrete.

(i) *Light Weight Concrete:* This type is of very wide application for panel walls of framed structures, blocks and slabs of partitions, hollow tiles or tubes in ribbed R. C. C. floors, etc. and wherever, not much strength but lightness combined with some degree of thermal insulation, and sound-deadening is required. For preparing this concrete, blast furnace slag is suddenly chilled by water while it is yet in a molten condition to form porous, vesicular texture and become light. It is crushed, mixed

*** These and many other new materials recent'y introduced have been dealt with in detail with their prope-ties and methods of manufacture in the book *Materials of Construction* by R. S. Deshpande.**

with cement and water, and moulded into slabs or blocks of the required size. Such a slag is called "foamed" slag. Concrete made of coal ashes and breeze, called "breeze concrete" is unsound.

(ii) *No-fines Concrete:* In this the usual fine aggregate of normal concrete is omitted and coarse aggregate, ei her gravel, broken stone or crushed blast furnace or boiler clinker, varying from 10 to 20 mm. (3/8 to 3/4 in.) in size is used with cement in the proportion of 8:1 or 10:1 and moulded into blocks or bricks. Though the crushing streng h is not much, it can be safely used for load bearing walls or residential houses up to two storeys high. If used in the external walls a rendering of cement plaster is required on the exposed face and there is always the usual plaster, or plaster board lining on the inner face. The concrete holds large spaces of air which are thus sealed between the coverings on the face and back; the walls provide fairly good thermal insulation, besides being cheaper and lighter.

(iii) *Aerated or Cellular Concrete:* This is made by using either certain chemical substances in the mix, which emit gas bubbles during the process of hardening, or introduction of air bubbles by some mechanical means. The aggregates are fine, either grit, or crushed foamed slag. The concrete weighs from 725 to 1000 kg./m.^{3} (45 to 60 lb./ft.^{3})

If still lighter concrete weighing 325 to 500 kg./m.^{3} (20 lb. to 30 lb./ft.^{3}) is required, it is made of foamed cement with very little or no fines. For still lighter concrete, aluminium powder, 800 to 1000 parts to one part of cement is mixed with water to form a paste. The latter is poured into moulds to one-third of their thickness. A chemical reaction takes place, liberating hydrogen in the form of bubbles, which cause the paste to swell and fill the mould.

This concrete is used for rendering walls of acoustic plaster in theatres, encasing hot water or steam pipes, as an insulating layer on top of terraced roofs, and in the construction of prefabricated aluminium or steel houses. A layer of this material on aluminium, or rust-proof steel sheets used for external walls, affords excellent insulation from heat.

Extra light-weight concrete is liable to crack while either drying out or becoming wet on account of sudden change in its volume. This tendency is much reduced if the concrete, while yet in moulds, is cured with steam.

2. **Cold-Worked Reinforcement:** If a bar of commercial mild steel is stretched beyond its yield point, and then released, it will be found not to have a yield point at all and then it can be subjected to loading, causing higher stresses in it. 10 mm. (3/8 in.) and thinner bars, thus axially stretched are called "hard drawn wire" (covered by B. S. S. 785). Square bars up to 22 mm. (7/8 in.) size if stretched beyond yield point and at the same time twisted, make high tension bars which allow a higher bond stress in addition on account of its irregular surfaces. In one patent reinforcement, called "Isteg steel," two round or square bars of mild steel are placed side by side, stretched and twisted to form a sort of rope.

Pressed Steel Thin Welded Sections: Thin, flat strips or plates of mild steel, 1·5 to 2 mm. (12 to 18 gauge), can be pressed cold and formed into shapes of some of the rolled sections, such as angles, channels, zed sections, etc. By the process of cold working they become still harder and stronger. Two such channels can have their backs welded together to form I-sections with broad flanges. Innumerable varieties of thin steel sheets can thus be formed by pressing and welding. These have a very large number of structural uses in buildings of one or two storeys, for frames of partitions, flooring, ceiling, roofing, or even for walls of 'prefabs,' if the necessary heat insulation and rust-proofing is effectively made. These have been used actually on a very large scale in the construction of prefabricated houses.

3. **Glass:** Reference has been already made in the text to glass bricks and paving blocks or lenses for producing day-light conditions in cellars or attic and also to reinforced glass work which has made some more progress in recent years in the improvement of the technique.

Fibre-glass Bitumen Bonded: Molten glass is passed through minute jets to be drawn into long, thin fibres by steam, the resulting mass is impregnated with bitumen emulsion, and finally compressed into sheets, 25 mm. (1″) thick, 10 to 15 m. (10 to 15 yards) long, and 80 to 120 cm. (33 to 45 in.) wide. These sheets can be cut with a knife or a pair of scissors. It weighs 125 kg./m.^{3} (8 lb./ft.^{3}) and has a thermal conductivity of 0·23. It can be had in thinner sheets also just like cloth in strips.

Besides being used for sound-deadening and thermal insulation, in walls, floors, and ceilings, it is equally efficient as a lag-

ging for hot water or steam pipes, and hot water cylinders. Being 100 per cent glass, the material is resistant to high tempera'ure and to attack by acids, oil, sea water, etc., and is non inflammable.

Thermolux is a compound glass consisting of a thin mat or layer of glass fibres between two sheets of ordinary glass, which can be sheet, plate or other varieties. It forms a perfect diffusing medium both for daylight or artificial lighting, and provides very good thermal insulation, eliminating heat and also glare. It also provides complete obscuration for privacy. It is thus useful for roof glazing, windows, partitions, etc. With this it is no longer necessary to admit light only from the North direction in schools and factories.

4. **Timber:** Great advances, in the utilization of timber have taken place recently during the last two World Wars, though it is one of the oldest structural materials known to man. Wood is a sort of plastic made by nature by utilizing cellulose, which is a carbohydrate, and lignin, a very strong complex adhesive. Weight for weight, it is superior to steel in tension, flexure, and stiffness, but inferior in direct compression and shear.

The great disability of timber is that, unlike steel, which is a manufactured product, the quality of which can be guaranteed to be uniform, timber, being a natural product, is subject to a wide range of variation. Timber does not possess the same strength in the direction at right angles to the grain as in that parallel to the grain. This is overcome by lamination.

Lamination in a general sense, consists of securely fastening thin, short pieces of wood together by either nailing, bolting, gluing, or other suitable means, and placing them in such a way that they will act as one member. If this is successfully done, the working stress determined for single members can be increased according to the number of laminations. In the case of wood, synthetic adhesives, such as phenol or urea formaldehyde or cellulose resins are used. For members used in exposed situations the former two are used. Cellulose resins are cheap, but are affected by moisture and heat.

Plywood is a highly specialised form of lamination. In it the longitudinal grain is provided both lengthwise and crosswise in alternate plies in panel, so that high strength is obtained in both directions. It is manufactured in sheets $1 \cdot 25$ m. $\times$ $2 \cdot 50$ m.

(4′ × 8′) and 8 to 30 mm. (3/16 to 1¼ in.) in thickness consisting of 3 to 9 plies.

There are three different forms of plywood, viz. (1) Plywood made by bonding together three or more veneers of wood by an adhesive, (2) laminboard, in which a multiply panel of plywood is recut edgeways, glued, and laid between outside plies of thick veneers and pressed into sheets of 8 to 50 mm. (⅜ to 2 in.) thickness, and (3) battenwood, the panel of which is similar to laminboard in construction but the core is made from solid battens 20 to 25 mm. (¾ to 1 in.) thick. The total thickness is the same as that of laminboard.

In addition to the numerous uses to which plywood is applied, its main structural uses are in (i) webs of built up wooden girders, arches, and all diaphragms subjected to shear for which plywood boards 25 to 50 mm. (1 to 2″) thick are used and (ii) gussets in framed and glued wooden trusses. The various members are glued to plywood boards and sometimes further reinforced by nailing or bolting.

The principle of lamination is applied even to a greater advantage in making laminated beams by bonding together wooden boards 25 to 40 mm. (1 to 1½ in.) thick parallel to the plane of bending.

5. **Building Boards and Sheets:** The material used for these may be either of the nature of fibres, chips, or pulp. It may be also of either vegetable origin (cellulose) like wood fibre, chips, weeds, sugarcane bagasse, husks, shells, etc. or mineral like asbestos and cement. There are several grades of such insulating boards, hard-boards, laminated fibre-boards, etc. Boards of laminated paper also are manufactured. Amongst boards, Masonite deserves a special mention. For this, waste wood chips of any variety of wood are put into an air-tight steel vessel called, 'gun,' steam is introduced into it at first under a pressure of 350 to 425 kg./cm.^{2} (500 to 600 lb./in.^{2}) and then the pressure is suddenly increased to 700 kg./cm.^{2} (1000 lbs.) just for five seconds and a valve at the bottom is opened, when the chips are discharged with great force through the gun, causing them to "explode" with great noise. As the pressure is suddenly released, the wood fibre is separated under the influence of moisture and heat from the natural adhesive called lignin. The spongy fibre is spread out on

screens in mats of the required thickness and rolled, under heat and pressure, so that the lignin binds the fibre and the result is a very strong and stiff board or sheet.

6. **Plastics:** Plastics combine the qualities of glass, timber and steel, in so far as they are clean, glossy, decorative in colours, not affected by heat, moisture, vermin, rot, or acids. They can be cut, nailed, screwed, or punched and some of them are very hard. With all these advantages, however, they cannot and will not replace the structural materials. In the first place their modulus of elasticity is very low which would cause excessive deflection, and secondly, their cost is comparatively high. Their use as a complementary material is very valuable, as a material of decorative art and as an insulating material. Their use as adhesives in making beams and other structural members with paper, timber and other like materials is however, a very great asset to the engineer.

Two new plastic materials recently introduced are likely to revolutionise the building trade. They are:

(i) **Perspex:** It is just like glass, but can either planed, sawn, and drilled. It is available in sheets of 1 to 3 m. (3 to 10 ft.) length either plane or corrugated, clear as plane glass or opal as frosted glass. It weighs less than 15 kg./m.^{3} (a lb. per cub. ft.) and is tough and durable. The corrugated sheets can be used just like g.i. sheets for roofing. The opal sheet transmits 80% of the light. It can be painted or sprayed with cellulose paint for decorative effect.

(ii) **Alkathene or Polythene** in the form of a thin film has been already described on page 278. Its other use is in the form of a service pipe from 5 to 50 mm. (¼ in. to 2 in.) diam. available in coils 150 m. (500 ft.) long. The pipes can be bent as desired. For normal gauge thin pipes special brass fittings such as elbows, tees, straight and reducing sockets are available. Slightly thicker gauge pipes can be threaded and used with ordinary g.i. fittings. They can also be butt welded or joined with spigot-and-socket joints. They can be used for conveying cold or hot water up to 60°C (140°F), oils or any alkalis and acids, except the acetic and sulphuric acids. They do not rust when buried underground.

Epoxy Resins: The basic epoxy resin is synthesized from two widely available reactants: (1) epichloro-hydrine, and

(2) bisulphenol A. To this are added (a) some plasticizer, like polysulphide liquid polymers, to impart flexibility, (b) fillers, such as clay, coal tar, asbestos, mica, silica etc. according to the desired qualities, such as hardness, elasticity, delay in setting time etc. Incidentally it also increases bulk, and reduces cost. (c) diluents such as aromatic solvents, and (d) curing or hardening agents, such as amines, organic acids and anhydrides.

Properties: *Adhesion.*—It sticks to metals, wood, glass, concrete, ceramics with equal ease at contact pressures. Its adhesive strength is at least 7 times as much as that of phenolic resins, in tension, compression, and impact. It can be used at room temperature, its shrinkage while hardening is very low, and can be still further reduced by the addition of a suitable filler. It is resistant to moisture, acids, alkalis, salts, solvents, heat and electricity. It cures or sets very quickly. Roads surfaced with it can be opened to traffic within two hours.

Uses: These resins can be used in construction joints, for bonding new to old concrete or masonry. A coating of the resin to reinforcing steel bars increases the bond as much as five times as that with uncoated surface. It can be used for attaching precast elements of concrete, or steel, or other fittings, or masonry plane surfaces. Concrete or steel pipes coated with epoxy resin give a smoother surface and protect them from corrosion and abrasion. It can be used for grouting anchor bolts, sealing cracks, in masonry or concrete, patching and repairing plasters, repairing pot holes in road surface, etc.

Handling Precautions: Many uncured epoxy resin compounds are toxic. The mason should use a pair of rubber, or plastic gloves; a sprayer should use a respirator, and should not expose skin in any part.

Araldite is a patent name for these resins manufactured by the CIBA, India, Ltd.

HINTS ON INSPECTION OF BUILDINGS : 22

(1) **Order Book:** Maintain a machine numbered order book on site, and record all the orders in it under dated signature. As far as possible, no instructions should be given verbally. If any are occasionally given in hurry, the subordinate, or the Mistry in charge, should be asked to get them confirmed in writing at the earliest opportunity.

(2) **Siting:** Check the minimum distances required on the front, sides and back of the proposed building according to the Local Bye laws.

(3) **Foundations:** Check right angles by comparing the diagonal distances, which should be equal. Bottoms of trenches should be horizontal. Check depths and widths at a few doubtful places. No loose earth to be allowed. Black and white ants' nests to be dug out.

(4) **Concreting:** Check specified proportions of ingredients, thorough mixing; layers not to be too thick, ramming to be sufficient until cream of lime comes to the surface. No screeding of mortar on surface to be allowed. Top surface of every course to be horizontal. Completed work to be profusely watered, and kept wet at least for two weeks or till masonry is started. Cement concrete to be rammed for half an hour after it is placed and then to be left undisturbed.

Mortar: Ascertain and check proportions of ingredients. If lime mortar, grinding must be sufficient. *Surkhee,* if used, must be passed through a sieve of correct size. If cement mortar, mixing must be perfect—dry mixing twice, wet mixing thrice again. Just sufficient quantity for half an hour's use to be wet-mixed.

(5) **Masonry (Stone):** Upon arrival on work first inspect tops of walls, more particularly those reached by ladders and

see that there is a cross bond between the facing and backing in the form of overlapping tails of stones, and through stones or headers.

See that strings and plumbs are used by masons, and that every mason is supplied with a keg of water, for wetting stone before it is set in mortar. Remove a few stones, from the hearting to verify that no hollows are left and that every chip is set in mortar, i.e. no two surfaces of stones come together without mortar between them.

Coursed Rubble Masonry: Check length of tails of *Khandkees*. Check headers which should be marked by a cross mark on the face, and see that they are at the specified distance apart in every course, and staggered in any two successive courses. Check the dressing of beds of *khandkees* and corners to see that it is as specified.

Uncoursed Rubble Masonry: Do not allow any stone on face which is more than 20 cm. (8″) in height. It is sure to have been laid on edge, i.e. with tail smaller than the height. Headers are more important in uncoursed rubble masonry.

Test vertical faces of masonry by a plumb bob. The waviness on the surfaces can be detected by standing away in line with the face or the back of walls. Make sure that no hollows are left in the work.

Brick-work: See that a perfect arrangement has been made to soak bricks in water. Inspect tops of walls to see that no bats are used. Bond to be correct especially at corners. Test vertical joints at a few places with a trowel, to verify that they are properly flushed up. Bed joints to be horizontal, and not too thick. Too much water not to be allowed in mortar. See that proper arrangement has been made for watering on the top.

Jambs of doors and windows to be vertical.

Skewbacks of arches and tops of walls to be properly cut and not filled with chips or bats in mortar. Joints of arches to be even.

Condemn scaffolding or ladders which are rickety.

Interiors of chimneys to be pargetted smooth, no woodwork to be allowed near flues. See that putlog hoies do not

weaken walls and that they are neatly filled and plastered before scaffolding is removed.

Wood-work: Test verticality of posts and frames of doors and windows. This can be done by standing at a distance and watching, and applying a plumb bob where doubt arises. Check quality of timber used as per specifications. Door and window frames to be painted with coal tar on the sides going into masonry.

Doors and window shutters to be made and kept ready at an early stage of the work and neatly stacked in a shed for seasoning by aeration, so that they may shrink and season to some extent before the joints are finally tightened up.

While making the shutters of doors and windows, a good clearance should be left between the two sides of the rebate in the frame and the edge of the shutter, so that when the wood expands, the shutters may be closed without difficulty, and without bringing any extra strain on the hinges.

Plinth filling to be well rammed and watered in layers.

See that lintels have a sufficient bearing on side walls.

Check and verify whether templates and bed plates of sufficient size are provided below beams.

R. C. C. Work: (General) All steel to be according to I. S. S. and not rusted, cement fresh and aggregates clean. If not, washing should be insisted upon. Proportions of ingredients to be as specified, and mixing thorough. If hand mixed, the mixture should be turned over twice dry, and three times again when watered. Just the necessary quantity of water to be used, and concrete laid within half an hour after the moment water is first added to the dry mixture.

Consistency of concrete to be just sufficient to make it workable, and no more. It should be even less if vibration is specified and resorted to.

Columns: See that grillage of proper reinforcement is provided in the footing. The dowels must be of such a length that an overlap of at least 24 diameters is obtainable where splicing is made. The latter should be made only at plinth and floor junctions. See that the vertical main reinforcement is in plumb and remains so while the column is being concreted, also that the

column is filled in one operation from the top of lower floor to the soffit of the beam of the upper floor.

The centre line of the columns one above the other on different floors, should be the same. If not, it causes eccentricity and bending stresses in columns.

Beams: Check the steel in longitudinal, diagonal and stirrup reinforcement, and check the bends as per design. See that the distances or spaces between rods, especially at junctions with columns, are sufficient to pass the aggregate freely. Finer aggregate and richer mix should be used at such places. See that proper bed plates, preferably of plain or R. C. blocks, are provided under beams on top of walls.

Slabs: Check diameters and distance apart of reinforcement as specified on drawings. Check the distance from supports to where the bottom rods are bent upwards. These distances are different for simply supported single spans, two spans and continuous slabs.

Another important point is to measure the vertical distance between the bottom of bottom reinforcement, and the top surface of the top reinforcement. In common practice, unless the engineer in charge pays particular attention, this will be 5 to 7 cm. (2 to $2\frac{1}{2}$ in.) even in a slab 12 cm. (5 in.) or more in thickness. This means that with no saving in materials or labour, the strength of the slab is reduced by at least 30 to 50 per cent. If there is some sort of tiling or even Indian Patent stone to be made on the top, this distance should be just 12 to 18 mm. ($\frac{1}{2}$ to $\frac{3}{4}$ in.) less than the thickness of the slab. Thus for a slab 12 cm. (5 in.) thick it should be 10 to 12 cm. ($4\frac{1}{4}$ to $4\frac{1}{2}$ in.)

Balconies and Other Cantilever Slabs: Verify that there is sufficient anchoring provided to balance the load on the cantilever beam or slab, especially in the case of a balcony more than 1·5 m. (4 ft.) wide. The thickness of a cantilever slab at the support should be $=\frac{\text{span in cm.}}{7\cdot 5}$ It is safer to use bars 12 mm. ($\frac{1}{2}$ in.) or more in thickness for balconies, and cantilever slabs of more than 1·5 m. (4 ft.) span, so that, while concreting they are not likely to be bent towards the bottom under feet of workmen, resulting in subsequent cracks on the top.

Iron Work: Check sizes of rolled sections, see that there is no rust beneath the protecting coat of paint or tar. Test rivets in trusses and see that one heel plate is slotted for expansion and contraction and is thus free to move. See that bolts are neither too short, nor longer than a couple of threads. Inspect welds carefully. Check the quality of electrodes before welding is started.

Roofing: See that all the timber is good as per specifications. Inspect bed plates under trusses. These should not come over door and window openings. Inspect anchor plates to protect light roofs such as of asbestos cement, or c. i. sheets from being blown by wind. These are often forgotten. See that the holes in c. i. sheets are properly made and are on ridges. Inspect joints of wooden trusses, purlins, and common rafters. See that ridge tiles are properly set in mortar.

Flooring: The surface should be even. Water should be poured on top, when it should flow easily in the direction of the holes left in walls for outlets for wash water, without stagnating anywhere. Step on a corner of a slab which has just been laid to test that it is well flushed with mortar underneath.

Plastering: Joints to be raked at least 25 mm. (1″) and the surface to be soaked with water. If it is lime plaster in three coats, see that after the second coat, the wall surface is well beaten. Condemn plaster which shows "blowing" or sounds hollow when tapped.

White and Colour Washing: See that it does not come off when rubbed gently with fingers, and that the colour is even and uniform throughout. All splashes of white and colour wash and plaster on wood work and glass to be cleaned.

Glazing: See that glasses of exact sizes and weight are used. Putty should be neatly applied in straight lines.

Painting: Do not allow painting on a damp surface. See that the proper number of coats is being given and the proper brushes are used. Examine the quality and brands of paints and see that they are as per specifications.

General: Do not take anything for granted, or assume that even the simplest work will be properly carried out.

And last of all—**be reasonable in the interpretation of specifications.**

APPENDIX No. 1

USEFUL MEMORANDA

The following information will be of service for calculations in design.

(1) Economic Leads :

Head load	....	....	10 m. (33 ft.)
Wheel barrow	....	....	20 m. (66 ft.)
Donkey	....	....	400 m. (2 furlongs)
Bullock cart	....	....	800 to 1600 m. (½ to 1 mile)
Motor truck	....	....	0·8 to 80 km. (½ to 50 miles)
Railway	....	....	beyond 80 km. (50 miles)

(2) Weights and Volumes: (approx.)

Stone ballast	$0 \cdot 62$ m^3 = 1 tonne.	(22 cu. ft. = 1 ton)
Gravel	$0 \cdot 65$ m^3 = 1 tonne.	(23 ,, = ,,)
Sand	$0 \cdot 595$ m^3 = 1 tonne.	(21 ,, = ,,)
Shingle	$0 \cdot 68$ m^3 = 1 tonne.	(24 ,, = ,,)
Cement	1 m^3 = 1200 to 1400 kg.	(1 ,, = 90 lbs.)
Slaked lime	1 m^3 = 400 to 600 kg.	(1 ,, = 60 lbs.)

(3) Increase in Bulk:

Earth when dug from a pit increases 25%
Sand and gravel ,, ,, ,, 20%
Sand with moisture 5 to 10% ,, 5 to 40%

(4) Shrinkage Allowance of Earthwork:

Earth and clay	....	....	10% height
Sandy and loamy clay	....	....	15% ,,
Sand and gravel	....	....	2 to 3% ,,

(5) Allowances for Voids in Measurements:

Phara of sand 14 in. ht. is measured 12 in.
,, ,, metal 13 ,, ,, ,, ,, 12 in.
,, ,, earth 15 ,, ,, ,, ,, 12 in.
,, ,, muram 13½ ,, ,, ,, 12 in.

(6) Proportions and Volumes of Cement Concrete:

1 cu. ft. of cement	: 2	:	4 makes	4.3 c. ft. concrete		
1 " " " "	: $2\frac{1}{2}$	:	5 "	5 "	"	
1 " " " "	: 3	:	6 "	5.8 "	"	
1 " " " "	: 4	:	8 "	7.5 "	"	

1 " " " " with 0.36 c. ft. water makes 0.825 c. ft. paste.

(7) Materials Required for 100 c. ft. of Masonry:

Uncoursed rubble masonry	120 c. ft. stone	33 c. ft. mortar
Coursed rubble "	130 " " "	25 " "
Ashlar "	110 " "	8 to 10 " "

Brick work:—Bricks $2\frac{5}{8}$ in. thick with $\frac{3}{8}$ in. joint, 4 layers in a foot and 5% wastage 1420 Nos. 24 c. ft. mortar

(8) Timber International Units:

Petrograd standards	165 c. ft.	1320 sq. ft.	120 Nos. $\times$ 12′ $\times$ 11″ $\times$ $1\frac{1}{2}$″
London standards	270 c. ft.	1080 sq. ft.	120 Nos. $\times$ 12′ $\times$ 9″ $\times$ 3″

50 c. ft. = 1 ton

(9) Materials Required for 1 : 2 : 4 Concrete Slabs for Floors or Roads per 100 sq. ft.

Thickness of slab in.	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	$6\frac{1}{2}$	7
Cement cu. ft.	7.32	8.24	9.15	10.07	10.98	11.90	12.82
Sand cu ft.	14.16	16.43	17.69	20.24	21.24	23.90	25.67
Coarse material cu. ft.	28.32	32.86	35.38	40.48	42.48	47.80	51.34

(10) Proportions and Volumes of Mortars Produced:

C. ft. of sand mixed with 1 c. ft. of cement	1.0	2.0	3.0	4.0	5.0
Volume of slush mortar	1.4	2.17	2.64	3.82	4.65
Volume of dry facing rammed mortar	1.22	1.93	2.64	3.35	4.08

APPENDIX No. 2

TABLE NO. 42

WORKING STRESSES IN STRUCTURAL STEEL

(L. C. C.)

Kind of Stress	Working Stress kg./cm.^{2}
Tension	1250
Compression	1250
Shear in Webs	800
Bearing on plates	1875

TABLE NO. 43

WORKING STRESSES IN RIVETS AND BOLTS

Kind of Stress	Shop Rivets kg./cm.^{2}	Field Rivets kg./cm.^{2}	Turned and Fitted Bolts kg./cm.^{2}	Black Bolts kg./cm.^{2}
Tension	800	650	800	1300
Single shear	950	800	950	650
Bearing	1875	1600	1875	1300

For Double shear twice the value of Single shear given above.

GENERAL INDEX

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